MANITOBA HAZARDOUS WASTE MANAGEMENT CORPORATION
SYSTEM SCOPE AND TECHNOLOGY STUDY

FINAL REPORT
PART I - STRATEGY REVIEW

Prepared by

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in association with

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Kansas City, Missouri

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Manitoba Hazardous Waste Management Corporation
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Attention: Mr. J. McCabe, P. Eng.
Senior Project Engineer

Dear Sirs:

RE: System Scope and Technology Study
Part I - Strategy Review

We are pleased to present twenty (20) copies of our Final Report on Part I - Strategy Review.

We wish to express our sincere appreciation for the valuable input provided by yourself, Mr. RJ. Cooke, P. Eng. and the other personnel from the Corporation during our workshop session and review of the draft report. We look forward to continuing to work closely with you on the completion of Part II and Part III of the study.

Yours truly,

D. Taniguchi

D.J. Taniguchi, P. Eng.
Project Manager

DJT/llh

Encl.

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SUMMARY

INTRODUCTION

The Manitoba Hazardous Waste Management Corporation (the Corporation) is charged with the responsibility of implementing a hazardous waste management system in the Province of Manitoba. In March 1988, the Corporation engaged the services of Reid Crowther & Partners Limited, in association with B&V Waste Management, Inc. to conduct a three part System Scope and Technology Study. Part I of the study is documented in this report and involved a review of the planning work performed to date and an evaluation of the Corporation's development strategy.

METHODOLOGY

As a planning level effort, the evaluation was based on a review of the literature and on the consultants' experience with hazardous waste planning, management, and engineering. To assure the most useful critique possible, a detailed discussion of the approach, criteria, and related topics was held during a workshop session. The workshop, an alternative screening and ranking exercise carried out jointly by Corporation and consultant personnel, elicited many useful insights into the planning process for all involved. The workshop also provided Black & Veatch with a better understanding of the Canadian and Manitoban perspective and of the specific characteristics of the problems and issues being addressed.

This report attempts to present varied and sometimes opposing points of view and strategies. In order to do so as briefly as possible and without confusing the issues involved, this report has artifically assumed that there is no middle ground and therefore issues are clearly "black or white". The reader is assured that nothing could be further from the truth and that this is merely an expedient way to document the activities performed during the strategy review.

To facilitate evaluation, the development strategies were visualized as made up of three logical components:

- the mechanisms or business vehicles used;
- the rates of development employed; and
- the geographical locations in which the activities take place.

Based on ownership or funding source, three business development options were identified, namely, a public corporation(s), a private enterprise(s), and a joint venture(s) of the two. The only two options possible in terms of rate of development are incremental (which may be at a variable rate) and immediate. Only three general location options were considered, namely in Manitoba, outside Manitoba, or a combination of both.

EVALUATION RESULTS

The evaluation results, including those modifications based on the information gained during the workshop, are summarized below:

- The Corporation's overall approach is excellent. It is a straightforward, well thought out, methodical strategy.
- A public corporation is a more practical alternative than private enterprise since the profit motive may deter the latter from addressing the total problem.
- A public corporation imposes limitations in terms of flexibility and reliability, because it does not have complete freedom of action nor can it respond as rapidly and effectively as private enterprise can. In this respect, a joint venture offers a good recourse since the Corporation can use its private partner to make up for its own deficiencies and weaknesses. This requires a balance between the profit and public service motives that can work in opposition in a joint venture.
- Although the total investment cost is the same for all business options, a public corporation requires the highest investment expenditure from the public purse and private enterprise requires the lowest. Here again, a joint venture would be a good trade off to minimize expenditures.
- The incremental approach provides more flexibility than immediate development and is the most practical solution to the many uncertainties and sides of the hazardous waste problem that require directed and concerted action.

- The incremental approach imposes limitations on some users by not providing the quickest solution to their problem and in fact increases their liability as time goes by without a complete waste management system. Conversely, the incremental approach may provide enough of a solution for other users (i.e. recycling and storage) and do so in a quicker time frame than the immediate approach which requires some time for building of the facilities. The number of users that would benefit by the incremental approach will be increased if the Corporation can arrange for some interim means of collection, storage, transportation and treatment of as much hazardous waste as practicable during the incremental development of the facilities.

- The incremental approach is nominally more costly because it takes longer and cannot capitalize on economies of scale. It also imposes a definite cost on the users by postponing solution of their problems. On the other hand, the incremental approach minimizes the risk of making the wrong capital investment, and is therefore a safer investment approach.

- A decision as to location of the activities and facilities required by the hazardous waste management system requires elements of judgment and information on type and size of facilities not presently available. However, the analysis indicated that there are several factors which favour locating all facilities within Manitoba and several factors which favour locating all facilities outside of Manitoba. Furthermore, it appears that the utilization of capabilities both within and outside of the Province will result in an optimum solution, both functionally and environmentally.

RECOMMENDATIONS

Analysis of the several development options provided some insights and information that are best summarized in the two recommendations below:

- Marketing, economic, and characterization studies to better determine the present and future hazardous waste types, waste amounts, markets, and service demands should be undertaken as soon as possible. These will establish the type and size of facilities required, thus enabling the location option decisions needed to complete the strategic planning process.

- Some form of joint venture(s) between a public corporation and private enterprise offers many advantages, enough to seriously warrant its consideration. There are many variations and levels of association which can easily be integrated into the Corporation's current strategy and which could prove very useful, practical, and cost effective.

SECTION 1.0
INTRODUCTION

BACKGROUND AND PURPOSE

The Manitoba Hazardous Waste Management Corporation (the Corporation) is charged with implementing a hazardous waste management system in the Province of Manitoba. The Corporation has generated and is presently implementing a hazardous waste system development strategy that works from the waste source forward. Initially, it addresses waste reduction possibilities and development of collection and storage capabilities. Subsequently, once the need and scope are better defined, it calls for the installation of those treatment and disposal facilities as they can be justified.

In March 1988, the Corporation initiated a three part "System Scope and Technology Study". This report documents the activities of Part I of the study, which consisted of:

- Reviewing the planning work performed to date.
- Providing an objective and independent perspective of the Corporation's incremental development approach, focusing on its practicality and on any limitations and costs it imposes.
- Identifying alternate development strategy options, from both a business and implementation perspective, and discussing their relative merits.

FIRMS INVOLVED

Reid Crowther & Partners Limited, in association with B&V Waste Management, Inc. were engaged by the Corporation to carry out this study.

Reid Crowther is a Canadian consulting engineering firm which has been involved in the planning and design of all aspects of waste management systems. Reid Crowther has carried out several assignments in the hazardous waste management field, including the feasibility study on hazardous waste

management in Northern and Western Canada, and participation in the development of the Alberta Special Waste Management Facility.

B&V Waste Management is an American consulting engineering firm which specializes in the development of hazardous waste management systems. Much of B&V Waste Management's experience has been in the development of privately financed waste management facilities. In carrying out this strategy review, this previous experience allowed them to consider the development of the proposed waste management system from the private sector's perspective.

SECTION 2.0
DESCRIPTION OF ANALYTICAL METHODOLOGY

INTRODUCTION

The alternate system development strategies were visualized as being made up of logical components or "building blocks". A "building block" concept lends itself easily to generating alternate strategies by re-arranging the "blocks". The concept also provides a framework around which to fashion an objective set of criteria for the assessment and screening of development strategies. One need only to evaluate each "building block" separately in terms of "block" specific criteria established for the purpose.

GENERATION OF OPTIONAL STRATEGIES

Three basic "building blocks" were postulated:

- the mechanism or business vehicle involved;
- the rate of development; and
- the geographical location of the activities and facilities required.

The mechanism is the business vehicle within which the hazardous waste management system will operate. Only three possibilities were identified based on ownership or funding source, namely, a public corporation, a private enterprise, or a joint venture of the two. The rate of development (or staging) only has two options, incremental or immediate, recognizing that rate remains a variable within the incremental approach. Three general location options were considered; in Manitoba, outside Manitoba, or a combination of both inside and outside the Province.

Choosing between the multiple options of each of the "building blocks" generates alternate development strategies. The choice proceeds logically from mechanism, though rate of development, to location. Eighteen different strategies are possible in this way. Unfortunately, until more detailed

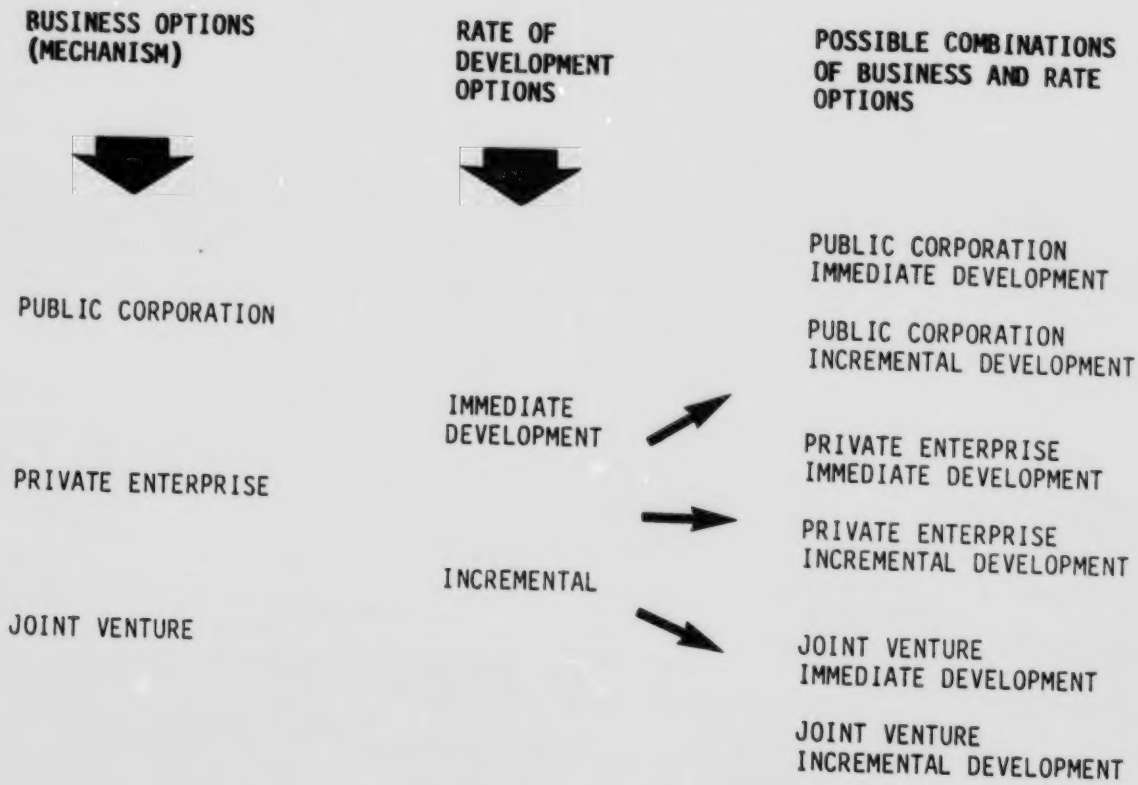

FIGURE 1
SIX POSSIBLE
OPTIONAL STRATEGIES

marketing and characterization studies define the required facilities and sizes, the location options cannot realistically be evaluated. Thus, at this time, there are only six major alternative courses of action, as illustrated in Figure 1, one of which is the Corporation's present approach.

GENERATION OF CRITERIA

A set of evaluation criteria was established for each of the "building blocks". The criteria were chosen for pertinence and relevance to the assessment of advantages or disadvantages of each building block. Some of the criteria (for example, least cost) are applicable to more than one "building block", although the meaning or context in which they are used may vary. The criteria and their intended meaning are provided below, grouped by "building block".

Business Option Criteria

Nine criteria were established for assessing business options (mechanisms), as follows:

- Total costs. Total costs are considered to include the following:

  Development costs - Planning and Feasibility Work
  - Project Management of Facility Development

  Facility Costs - Direct Costs of System Facilities
  - Indirect Costs Associated with Facility Support Infrastructure

  Operating Costs - Expense incurred during facility operation

  This criterion is intended to assess how total costs are affected by the business option selected.

- Financial feasibility. This meant the availability of funding, but it also covered resource availability, amount of subsidies, debt structure, initial funding, and repayment. This is more important than cost since it covers the capital requirements and how to recover them.

- Flexibility. This was used to imply the ability to handle varied waste streams, technologies, market conditions, and "new" issues.

- Reliability. This corresponded to the back up capability and the ease/adequacy of risk minimization to the public.

- Liability/accountability. The main element of concern was with the level of public comfort in the safe and reliable handling of the waste by each business option.

- User acceptability. This refers to the implied risk to the user (i.e. waste generator) due to the option.

- Safety/protection. Refers to the level of risk to the public and environment.

- Public acceptance/credibility. This reflects confidence and trust in the business option.

- Ease of site selection. This translates into how easily the public accepts a facility siting given the business vehicle involved.

Staging Option Criteria

The rate of development options were assessed in terms of eleven criteria. Six of these (least cost, financial feasibility, flexibility, user acceptability, public acceptance/credibility, and ease of site selection) were used to evaluate the business options and have the same meaning and context. The rest are as follows:

- Flexibility of access to treatment. This second flexibility criterion refers to the opportunity of using facilities available under other jurisdictions.

- Liability. This addresses the level of general public liability (i.e. not accountability) incurred under each rate rather than the level of public comfort considered in the business options.

- Economic benefit. This refers to the ability to develop and increase economic factors such as income, capital, and output by stimulating and developing industrial capabilities and employment.

- Socio-political acceptability. This addresses society's resistance and/or reaction to change.

- Economic impact. This reflects on the real (rather than the perceived) and fact based effect of each development rate on the waste generator.

Location Option Criteria

For addressing the location options, fourteen criteria were established. The meaning of six (least cost, financial feasibility, liability, socio-

political acceptability, flexibility of access to treatment, and public acceptance and credibility) was the same as discussed in the previous option sets. The rest are as follows:

- Economies of scale. This addresses the opportunity to optimize capital and operating costs by increasing the facility's capacity by importing some wastes from other jurisdictions.

- Potential of lower capital investments. This addresses the opportunity to lower capital investment if some wastes can be exported.

- Economic effects. The location of activities and facilities required may have some economic effects on employment, income, income distribution, and provincial economic development.

- Perception of solving one's own waste problems. This is a very subjective but real consideration affecting location.

- Intergovernmental co-operation. This looks at how location appears to make it easy or hard to implement the business and rate options because of multiple proponents and regulatory requirements.

- Desirability of relying on other jurisdictions. Relying on or accepting wastes considers the impact of future inter-jurisdictional relations and changing conditions. For example, in the United States some states are in effect closing their borders to hazardous waste in spite of federal government pressure to the contrary. (See the Appendix for more background information).

- Socio-cultural values. This criteria attempts to measure Manitoban society's resistance to change and the NIMBY (not in my back yard) syndrome.

- Net environmental risk. This was added to address the real risk to the provincial environment concomitant with the various location options.

Summary of Criteria

The criteria for the three building blocks are summarized in the table following.

SUMMARY OF EVALUATION CRITERIA

BUSINESS OPTION CRITERIA	CRITERIA DEFINITION
LEAST COST	This was meant to encompass total (capital, O&M, intangibles, etc.) costs to the Province in terms of the public investment required.
FINANCIAL FEASIBILITY	This meant the availability of funding, but it also covered resource availability, amount of subsidies, debt structure, initial funding, and repayment. This is more important than cost since it covers the capital requirements and how to recover them.
FLEXIBILITY	This was used to imply the ability to handle varied waste streams, technologies, market conditions, and "new" issues.
RELIABILITY	This corresponded to the back up capability and the ease/adequacy of risk minimization to the public.
LIABILITY/ACCOUNTABILITY	The main element of concern was with the level of public comfort in the safe and reasonable handling of the waste by each business option.
USER ACCEPTABILITY	This refers to the implied risk to the user (i.e. waste generator) due to the option.
SAFETY/PROTECTION	Refers to the level provided to the public and environment by implementation of risk minimization methods.
PUBLIC ACCEPTANCE/ CREDIBILITY	This reflects confidence and trust in the business option.
EASE OF SITE SELECTION	This translates into how easily the public accepts a facility siting given the business vehicle involved.

STAGING OPTION CRITERIA	
LEAST COST	This was meant to encompass total (capital, O&M, intangibles, etc.) costs to the Province in terms of the public investment required.
FINANCIAL FEASIBILITY	This meant the availability of funding, but it also covered resource availability, amount of subsidies, debt structure, initial funding, and repayment. This is more important than cost since it covers the capital requirements and how to recover them.
FLEXIBILITY	This was used to imply the ability to handle varied waste streams, technologies, market conditions, and "new" issues.
USER ACCEPTABILITY	This refers to the implied risk to the user (i.e. waste generator) due to the option.
PUBLIC ACCEPTANCE/ CREDIBILITY	This reflects confidence and trust in the business option.
EASE OF SITE SELECTION	This translates into how easily the public accepts a facility siting given the business vehicle involved.
FLEXIBILITY OF ACCESS TO TREATMENT	This second flexibility criterion refers to the opportunity of using facilities available under other jurisdictions.
LIABILITY	This addresses the level of general public liability (i.e. not accountability) incurred under each rate rather than the level of public comfort considered in the business options.
ECONOMIC BENEFIT	Refers to the ability to develop and increase economic factors such as income, capital, and output by stimulating and developing industrial capabilities and employment.
SOCIO-POLITICAL ACCEPTABILITY	This addresses society's resistance and/or reaction to change.
ECONOMIC IMPACT	This reflects on the real (rather than the perceived) and fact based effect of each development rate on the waste generator.

SUMMARY OF EVALUATION CRITERIA (Cont'd.)

LOCATION OPTION CRITERIA

LEAST COST	This was meant to encompass total (capital, O&M, intangibles, etc.) costs to the Province in terms of the public investment required.
FINANCIAL FEASIBILITY	This meant the availability of funding, but it also covered resource availability, amount of subsidies, debt structure, initial funding, and repayment. This is more important than cost since it covers the capital requirements and how to recover them.
LIABILITY/ACCOUNTABILITY	The main element of concern was with the level of public comfort in the safe and reasonable handling of the waste by each business option.
SOCIO-POLITICAL ACCEPTABILITY	This addresses society's resistance and/or reaction to change.
FLEXIBILITY OF ACCESS TO TREATMENT	This second flexibility criterion refers to the opportunity of using facilities available under other jurisdictions.
PUBLIC ACCEPTANCE/ CREDIBILITY	This reflects confidence and trust in the business option.
ECONOMIES OF SCALE	This addresses the opportunity to optimize capital and operating costs by increasing the facility's capacity by importing some wastes from other jurisdictions.
POTENTIAL OF LOWER CAPITAL INVESTMENTS	This addresses the opportunity to lower capital investment if some wastes can be exported.
ECONOMIC EFFECTS	The location of activities and facilities required may have some economic effects on employment, income, income distribution, and provincial economic development.
PERCEPTION OF SOLVING ONE'S OWN WASTE PROBLEMS	This is a very subjective but real consideration affecting location.
INTERGOVERNMENTAL CO-OPERATION	This looks at how location appears to make it easy or hard to implement the business and rate options because of multiple proponents and regulatory requirements.
DESIRABILITY OF RELYING ON OTHER JURISDICTIONS	Relying on or accepting wastes considers the impact of future inter-jurisdictional relations and changing conditions. For example, in the United States some states are in effect closing their borders to hazardous waste in spite of federal government pressure to the contrary. (See the Appendix for more background information).
SOCIO-CULTURAL VALUES	This criteria attempts to measure Manitoban society's resistance to change and the NIMBY (not in my back yard) syndrome.
NET ENVIRONMENTAL RISK	This was added to address the real risk to the provincial environment concomitant with the various location options.

APPLICATION OF CRITERIA

The criteria were applied in two related but different ways: (1) as the basis for evaluation of the Corporation's strategy, and (2) as the basis for comparison of other strategies to the Corporation's, thus singling out major features and differences, and ultimately allowing a preferential ranking. The results of evaluating the Corporation's strategy are presented in the next section of this report. The results of the comparisons are presented in the last section of this report.

SECTION 3.0
CORPORATION'S INCREMENTAL APPROACH

GENERAL

Black & Veatch developed a summary interpretation of the Corporation's development strategy which highlighted the principal features and key characteristics of the approach. The summary's format was adapted to the "building block" concept in order to facilitate the analysis and comparisons described in the prior section. The same format was used to describe the other five hazardous waste development system strategies. As a background for discussing the evaluation results, the summary description of the Corporation's incremental approach is provided below.

DESCRIPTION OF THE APPROACH

The Corporation's development strategy was described in terms of the mechanism it used, the objectives of the mechanism, the rate of development and strategy guiding accomplishment of the objectives, and lastly, the possible location(s) where the proposed activities could take place.

Mechanism

The business vehicle used is a public corporation (i.e. commercial Crown corporation) responding through its Board of Directors to a Minister responsible. Its equity is held by the Minister of Finance and will be subject to the Accountability of Crown Corporations Act. Except for the above stipulations, it will be able to deal in hazardous waste just like any private corporation. (Although a public corporation was assumed for planning purposes, this does not preclude the use of other business options.)

Objectives

The objectives of the public corporation are:

- to establish, operate and maintain in accordance with all applicable laws in the province, a hazardous waste management system in Manitoba;
- to research, develop, establish, own, operate and maintain facilities for the transmission, reception, collection, examination, storage, treatment, recycling and disposal of hazardous wastes;
- to ensure that the hazardous waste management system is established, operated and maintained in a manner that will protect the health and safety of the public and preserve the environment;
- to ensure the protection of health and safety of the public and the preservation of the environment following the closure of the hazardous waste management facilities established as part of the system.

Rate of Development/Strategy

Development is taking place incrementally, working from the waste source forward. It will build on existing capabilities and initially address waste reduction possibilities to help quantify the real needs. Priority will be given to public involvement and development of consolidated collection, storage, and volume reduction capabilities. After the need and scope are defined via marketing/characterization studies, the required treatment and disposal needs will be satisfied in discrete stages by designing and constructing facilities or by contracting for treatment and disposal services.

Location

The treatment and disposal facilities may be located in Manitoba, outside of Manitoba, or both. All three options are equally likely. Some facilities development is assumed within the province to facilitate the collection and consolidation of waste. Only after more detailed studies and information defining the required facilities and their size are gathered can the optimum scenario be determined.

EVALUATION OF THE APPROACH

The Corporation's strategy was evaluated by applying the criteria set out in the previous section.

Mechanism

Cost was defined as total investment cost to the Province of Manitoba. In the Corporation's strategy, a public corporation could own everything and might therefore pay and fund everything. It would also receive revenue which would be put toward recovery of this investment. This total government control and ownership would be costlier to the public treasury than the other business options which would require less or no public funding.

Financial feasibility addressed funding availability for capital requirements. From this point of view, the choice of a public corporation (or any other public vehicle) is the best choice available because of the funding availability.

The public corporation vehicle has enough freedom of action (i.e. flexibility) to adequately change, modify and adjust its handling of variable waste streams and technologies.

The public corporation will have a high motivation to search out and apply methods to minimize risk to the population at large.

The public in general feels more comfortable with an arm of government in charge of the safe handling of hazardous waste since government is perceived as more easily held accountable and better able to absorb any associated liability.

The average user of the system (i.e. generators like industry, commerce) also perceives the implied long-term risk to his operation as less if the hazardous waste system is in the hands of the government. He considers his problem to be more completely and lastingly solved, with minimum repercussions and reservations.

Both the perceived and real level of safety and protection of the public and the environment is highest with a public corporation because it is charged with planning and providing enough risk minimization measures to ensure a problem-free operation.

As stated above, the public will accept a public corporation more easily than any other mechanism and will believe more strongly in it than it would believe in private enterprise or a joint venture.

For many of the above stated reasons, but mostly because of the public's perception of government with regard to the liability/accountability, a site selected by government has an easier time being accepted by the community than a site selected through the other two mechanisms. There is also an underlying sense of "government has your best interests at heart", and enough cynicism to think "government will have its way over any and all objections". Private enterprise, on the other hand, is always suspected of sacrificing the public interest on the altar of profit maximization.

Rate of Development/Strategy

An incremental approach, by its very nature, will incur costs that would be avoided by the immediate approach. The real and imagined amount of liability is also greater since the longer it takes to develop and implement the system, the more the chances of damage increase. For the same reason, the users (i.e. generators and storers) are also at higher risk under an incremental approach. They prefer an immediate solution to their problem.

For most of the other criteria, however, an incremental approach is favoured. Since the level of expenditure and therefore the level of funding rises gradually over time, all of the financial feasibilty factors are attractive (i.e. less subsidies, less initial funding, etc.). The incremental approach is ideally suited to handle uncertainty because of the flexibility it provides. It allows enough time for waste streams and required technologies to be identified and quantified. It allows mid-course corrections and restaging, minimizing over or under building, and it can take advantage of developments in other jurisdictions and use their treatment and disposal capabilities for selected Manitoba waste streams. This mitigates some of the risks noted above to the public as well as the users.

An incremental approach also allows the staging of increases in the workforce for optimal effects and results. The methodical and gradual nature of the changes brought about make them easier to accept and less likely to be rejected. The public perceives an incremental approach as a reflexive, thoughtful, and purposeful approach to solving problems, less prone to wastage and more likely to come up with an optimal solution. The approach has a potential negative impact on siting because the full extent and magnitude of the facilities are not known beforehand by the potentially affected parties.

Location

The Corporation has yet to make a final decision with respect to location of all the involved activities and facilities, and is still engaged in reviewing the pros and cons of the available options. Our analysis of the fifteen location criteria favours Manitoba for five criteria, outside Manitoba for four, and a combination for the remaining five.

An all Manitoba location of the facilities offers the following advantages:

- minimizes the amount of intergovernmental co-operation required
- maximizes the general public's level of comfort with liability
- minimizes reliance on other jurisdictions
- maximizes the perception of solving one's own problems
- minimizes the public perception of transportation risk.

An all outside Manitoba location of the facilities offers the following advantages:

- minimizes the capital costs and funding disbursements to the Province, assuming there are no subsidies to potentially high cost waste generators. (However, a disadvantage is that operating costs are increased.)
- maximizes the potential for lower capital investments
- minimizes the Manitoban resistance to change
- minimizes the real net environmental risk to Manitoba.

A combination of inside and outside Manitoba provides the following advantages:

- maximizes the flexibility of providing more treatment and disposal opportunities than otherwise available;
- optimizes the economies of scale, because the capital and operating costs may be optimized by importing wastes;
- maximizes the Manitoban socio-political acceptability by spreading the activities, risks, liabilities, etc. to other jurisdictions;
- optimizes the economic effects on public and private sectors of the economy;
- will be easily perceived as the most credible option.

A combination of inside and outside Manitoba locations provides the best of both worlds. For those sites/activities located in Manitoba, you minimize intergovernmental requirements for co-operation and maximize public comfort with liability. For those sites/activities outside of Manitoba, you minimize costs and maximize the potential for lower capital investments.

SECTION 4.0
DESCRIPTION OF ALTERNATE APPROACHES

Summary descriptions were generated for the five other hazardous waste management system development strategies. The descriptions followed the same format used for the Corporation's approach, that is, they covered the mechanisms, objectives, and rate of development/strategies in order to show the salient features of each strategy. All five strategies are considered equal in terms of location because more detailed marketing and characterization studies are required before it can be determined which location is best.

PUBLIC AND IMMEDIATE OPTION

Mechanism

The mechanism and the objectives of this development strategy are the same as for the Corporation's development strategy, namely:

- The business vehicle is a public corporation; and
- This corporation will establish a hazardous waste system and will build the appurtenant facilities in order to protect the public and preserve the environment.

Rate of Development/Strategy

A comprehensive and fully integrated facility or a system of facilities will be developed directly. The Corporation will embark on exhaustive market and characterization studies to identify and quantify projected future hazardous waste streams. High priority will be placed on public involvement and on development of consolidated collection, storage and volume reduction capabilities. After the projected need and scope are defined, the required treatment and disposal facilities will be completely designed, installed, operated and maintained by the Corporation. Where advantageous, the Corporation could contract out for some component services such as transportation, transfer stations, and mobile treatment technologies.

PRIVATE INCREMENTAL OR IMMEDIATE OPTION

Mechanism

The mechanism is the same for both the incremental or immediate options, that is, a private corporation responding to a publicly sanctioned mandate. It will be subject to the laws and regulations relating to public corporations in the jurisdiction of its incorporation.

Objectives

The objectives of this private corporation, irrespective of whether it is incremental or immediate, are as follows:

- to establish, operate, and maintain a business in a profitable manner;
- to develop, establish, own, operate, and maintain facilities for the management of hazardous waste in accordance with prevailing laws and regulations;
- to protect the health and safety of the public and preserve the environment within the context of the first objective above.

Rate of Development/Strategy

Development for the incremental option will take place in logical stages of expansion corresponding to what prior analysis indicates the market will sustain. The Province will delegate responsibility for the design, construction, and operation of all the required treatment and disposal facilities to the private sector. High priority will be placed on public involvement as the key to ensuring approval of proposed facilities. Development of collection and storage capabilities will also be commensurate with the demand.

For the immediate option, a fully integrated facility will be developed directly after an exhaustive marketing analysis has indicated what the market will sustain. The Province will delegate responsibility for the

design, construction, and operation of all the required treatment/disposal facilities to the private sector. High priority will be placed on public involvement as the key to ensuring approval of proposed facilities. Development of collection and storage capabilities will correspond to the type and size of facility selected.

JOINT VENTURE INCREMENTAL OR IMMEDIATE OPTION

Mechanism

The business vehicle is the same for both the incremental or immediate options, namely, a public (commercial Crown) corporation responding through its Board of Directors to a Minister responsible in a joint venture with a private corporation(s) responding to its Board of Directors. Their respective equities will be held by shareholders (i.e. the Crown and private investors/institutions) and each will be subject to the applicable laws and regulations.

The joint venture would take the form of an operating partner (either private or public) for the whole system, or similar arrangements between a public corporation and different private investors for various system components or private and public equity in a separate mixed equity corporation that acts as the system developer and operator.

Objectives

The objectives of this broadly defined joint venture, irrespective of whether the rate of development is incremental or immediate, are as follows:

- to establish, operate, and maintain a hazardous waste management system with appropriate returns to the shareholders, measured in social and financial terms for the public partner(s) and in terms of profits for the private partner(s);
- to develop, establish, own, operate, and maintain facilities for the management of hazardous waste in accordance with prevailing laws and regulations;

- to protect the health and safety of the public and preserve the environment with the caveat that the private corporation(s) will do so in the context of the profit motive.

Rate of Development/Strategy

For the incremental option, the public corporation will take the lead and set an incremental pace for development, working from the waste source forward. The public corporation will build on existing capabilities and initially address waste reduction possibilities to help quantify the real needs. High priority will be placed on public involvement and development of consolidated collection, storage and volume reduction capabilities. Subsequently, after the need and scope are defined via marketing and characterization studies, private corporations will be invited to participate in some or all of the required facilities. Those system components for which no private investor is forthcoming will be satisfied in discrete stages by the public corporation either by direct development, design, construction, and operation or by contracting for those components on a commercial basis. Alternatively, the Corporation could enter into an agreement with private investors to jointly finance, develop, and operate all or some of the system through a jointly owned entity.

For the immediate option, the public corporation will take the lead and embark on a marketing study to identify and quantify the future waste streams as well as site identification and selection. High priority will be placed on public involvement and on development of collection and storage capabilities. After the need and scope are defined by the marketing study, private corporations will be invited to participate in some or all of the required facilities in joint venture with the Corporation. In order to minimize the total cost to the province, the public corporation may develop and operate some of the ancillary facilities, such as collection and storage.

SECTION 5.0
EVALUATION OF ALTERNATE APPROACHES

The evaluation of the five alternate development strategies was based on comparing each of them to the Corporation's approach. This comparison concentrated on presenting those aspects that were different (which means that similar aspects are not discussed). Only those criteria that are common to both the mechanisms and the rates of development are compared since the location options are common to all six strategies and no decision has been made in their regard. The analysis assessed the relative merits and disadvantages of each and ranked the strategies to identify the alternative most competitive with the Corporation's approach.

FINANCIAL ASPECTS

As explained before, because of the private ownership involved, both private enterprise and a joint venture would represent less investment by the Province of Manitoba than a public corporation, with private enterprise requiring the least public financial obligation. Expenditures in both cases represent less of a drain on the Province's financial capacity than the expenditures of a public corporation. Other things being equal, there is less economic impact on the generator from strategies with immediate rate of development than those with incremental, irrespective of which mechanism or vehicle is involved. The overriding factor is that the likelihood of damage and liability to the user increases in proportion with the time it takes to build and operate a hazardous waste treatment, storage, and disposal facility. On the other hand, the incremental approach implies early provision of some collection and storage facilities which might minimize the impact on some generators, particularly the small quantity generators.

ADMINISTRATIVE ASPECTS

A public corporation may generate the most liability to the Province, but as an agent of government, it is also the best able to absorb any liability

generated. It is also the most easily held accountable by the public. Private enterprise is viewed as being at the other end of the spectrum since there is a limit to the liability it can and will absorb and it is much harder to hold accountable. There is no difference between incremental and immediate rates of development in terms of liability.

In terms of flexibility to handle varied wastes and technologies and the ability to take advantage of facilities in other jurisdictions, the rate of development overrides the mechanism in importance because it controls the amount of time devoted to methodical planning implementation. An incremental rate is more flexible than an immediate rate of development irrespective of the mechanism. In spite of its freedom of action, private enterprise, because it pursues profit maximization, is the least flexible business option. A joint venture is at the other extreme because the public partner will balance the private component with tradeoffs between flexibility and financial risk mitigation.

Reliability in general is dominated by the mechanism; the effect of rate of development is only indirect. A joint venture is the most reliable business option because the public partner requests backups and risk minimization and the private partner efficiently provides it because the public partner can mitigate financial risk. Private enterprise is the least reliable business vehicle since this would run counter to the profit motive. For reliability, an incremental rate of development is superior because it allows planning and staging carefully.

SOCIAL ASPECTS

A public corporation is the instrument of choice with regards to user acceptability of risk, public acceptance, level of safety/protection, and ease of site selection. This is because it is perceived to be more trustworthy in the discharge of its functions and it is in fact charged with doing its best to satisfy the criteria. Private enterprise is the least desirable for the above criteria, mostly because it is expected to do less to satisfy these criteria in order to avoid reducing profits.

There is no rate of development preference regarding level of safety. There is, however, a preference for an incremental rate of development in terms of public acceptance, timeliness of increased employment, and socio-political acceptability. This preference is a function of the way the public perceives the incremental approach as thoughtful, purposeful, allowing optimal staging of work force increases, and minimizing the chance for rejection of proposed changes. There is a preference for an immediate rate of development in terms of ease of site selection because the affected parties know up front the full extent and magnitude of the facilities involved. User acceptability, because of increased liability associated with taking longer, is strongly biased towards an immediate rate of development regardless of the business option involved.

GENERAL COMMENTS

The analysis points out that a public corporation is the preferred vehicle, followed closely by a joint venture(s). Private enterprise by itself, despite the trend in the USA, is not a good solution for such an important and absolutely needed service. Despite this fact, there are some very good reasons for private involvement (mitigation of public cost, additional sources of funding, freedom of action, and efficiency) and they are also the reason why a joint venture emerges as a clear, workable, practical, and even desirable alternative. An autonomous public corporation could, in theory, provide the advantages of freedom of action and efficiency.

There is no doubt that an incremental approach is the best choice, especially in an environment where hazardous waste impacts have not yet reached proportions high or serious enough to merit immediate, all out remedial measures.

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APPENDIX

LOCATION OPTION FACTORS

There are many factors that affect a decision on a facility location. Two important factors which impact the decision on whether to locate facilities ouside of the Province are barriers to moving hazardous waste across borders and the level of development of facilities in border jurisdictions. Each is addressed below based on recent news items from the Hazardous Waste News (HWN).1

BARRIERS

The history of international agreements is both encouraging and discouraging. The International Joint Commission has been functioning successfully for years under the 1978 Great Lakes Water Quality Agreement. This is a prime example of how much can be accomplished towards solving a mutual environmental problem. Unfortunately, the "track" record on acid rain is not up to the same level of accomplishment and has become something of a political issue in both countries. It is difficult to foretell what the public and official reaction would be to transportating hazardous waste across international boundaries. Although there is fairly free movement of goods and materials, the fact that Polychlorinated Biphenyls (PCB) cannot be transported across international boundaries points out what the probable reaction might be. This is further supported by the reaction of some states such as Texas (HWN - 4/11/88, page 148) and Alabama (HWN - 5/2/88, page 180). The Texas Water Commission asked Congress to amend the Resource Recovery and Conservation Act to authorize state ban of hazardous waste imports from other states. Alabama signed a law forbidding construction of hazardous waste handling and disposal facilities unless expressly approved by the state legislature.

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1 "Hazardous Waste News", published weekly by Business Publishers, Inc., 951 Pershing Dr., Silver Spring, MD 20910-4464.

On the other hand, the EPA (HWN - 4/11/88, pages 145 and 146) is disposed towards interstate transport. The EPA not only opposes bans on interstate shipments of hazardous waste, it is concerned by a state tendency to limit shipments of hazardous waste by imposing higher disposal fees. EPA is expected to tie facility siting to superfund capacity certification (HWN - 4/18/88, page 160), that is, those states that close their borders to hazardous waste will have to prove they have reached their hazardous waste handling capacity.

Some state action is also in favour of shipment across boundaries as demonstrated by several southeastern and northeastern states, which are, with EPA help, planning regional approaches and facilities for hazardous waste management (HNW - 5/2/88, page 177).

In summary, the jury still seems to be out in terms of barriers to shipping hazardous waste across state and international boundaries. There are strong pressures for either side of the issue, at least in the U.S., and the final direction that may be taken by the Congress of the United States is unpredictable.

HAZARDOUS WASTE FACILITY DEVELOPMENT IN BORDER STATES

Neither of the two U.S. states bordering Manitoba (Minnesota and North Dakota) has hazardous waste facilities of any consequence. North Dakota (see telephone memorandum dated 4/7/88, to Martin Shcok of the State Department of Health) does not have any commercial or state owned facilities. It does not even have an official hazardous waste planning activity because it lacks the funds. Minnesota does not currently have any facilities but is moving rapidly to remedy this situation. The Minnesota Waste Management Board (HWN - 3/21/88, page 118) has introduced legislation that would change existing law to allow state or joint state and developer ownership of a hazardous waste stabilization and containment facility. More recently, (HWN - 5/2/88, page 179), the Board has recommended accepting an offer from IT Corporation and Chem-Security, Ltd. to build and operate a state owned hazardous waste facility.

MINNESOTA PANEL CALLS FOR STATE TO OWN WASTE TREATMENT FACILITY

Saying it wants to be sure that "high environmental standards" are met, the Minnesota Waste Management Board has decided to seek a change in the law that would allow the state to own a proposed multimillion-dollar waste stabililization and containment facility at a site that has yet to be selected.

Under current law, the state can purchase property and lease it to a private firm, which would own and operate the facility. The legislation, introduced March 3, would permit the facility to be wholly owned by the state or jointly owned by the state and the developer, who would operate it under a contract. State Sen. Gene Merriam is sponsoring the Senate bill; state Rep. Willard Munger has introduced an identical House bill. Munger chairs the House Environment Committee.

The board's staff has been negotiating since December with two teams of companies that submitted proposals to develop the plant. One team is International Technology Inc. and Chem-Security Ltd.; the other is Aptus-Westinghouse. The facility will treat ash from hazardous-waste incineration and sludges generated by circuit board manufacturing firms and metal-plating companies. The wastes, which are considered hazardous because they contain lead and other metals, are now shipped to landfills in other states.

Last month, the staff recommended state ownership to ensure the facility meets Minnesota's environmental requirements, which are stricter than federal standards under the Resource Conservation and Recovery Act. State ownership also would help limit the facility's size and the amount of out-of-state waste that would be accepted, the staff said. "After carefully reviewing all the options," said Board Chairman Joe Pavelich, "we think public involvement is necessary if the project is to meet Minnesota's high environmental standards while remaining economically viable."

Five counties have expressed interest in becoming the site of the facility, which is expected to employ about 25 people. In addition, the host county will be able to negotiate with the state for a package of long-term benefits, including tax breaks and road and community improvements.

NORTH CAROLINA BOARD MULLS SITE FOR TREATMENT FACILITY

The North Carolina Hazardous Waste Treatment Commission is debating potentially suitable sites for a comprehensive hazardous-waste treatment facility that could be state owned and operated. The panel may make a site selection announcement on March 25, officials said.

The legislature created the commission in 1984 to assess the state's waste-management needs and choose a site if no private companies came forth to build and operate a facility. The proposed facility would have two rotary kiln incinerators, a chemical batch treatment plant and a distillation system to recover spent solvents. The number of potential sites was narrowed from more than 500 initially to 13 by last September.

Meanwhile, a controversial state law passed in 1987 that sets a stringent new dilution standard for hazardous-waste facilities has come under fire from the Hazardous Waste Treatment Council. The industry group claims the statute violates the Resource Conservation and Recovery Act because it would effectively block the issuance of a permit for a commercial treatment facility that GSX Chemical Services has proposed to build in North Carolina.

EPA, GOVERNORS DRAFTING GUIDELINES
ON SUPERFUND CAPACITY CERTIFICATION

With 18 months until the certification deadline, the National Governors' Association is drafting guidelines for the Environmental Protection Agency on how states are to certify to EPA that they have the capacity to manage all hazardous wastes generated within their borders over the next two decades.

The 1986 Superfund Amendments and Reauthorization Act requires all states to assure EPA by October 1989 that they can manage their Resource Conservation and Recovery Act and Superfund wastes through the year 2009. States that cannot provide enough disposal capacity face the loss of all Superfund financing for hazardous-waste site cleanups.

Four NGA task forces are preparing the guidelines, which officials hope to submit to EPA next month. Some initial recommendations, if adopted by the agency, will prove critical to the success of the states' ability to comply with the law. One of the most important involves a recommendation to allow states to use waste-reduction programs to satisfy part of the capacity assurance. This means states will not have to rely entirely on the construction of new disposal facilities to prove they can manage their wastes, a process that involves political risks related to the siting of new hazardous-waste facilities.

NGA officials also have recommended that on-site and commercial recycling be considered "waste minimization." They defined recycling as "the use or reuse of a waste as an effective substitute for a commercial product" and the reclamation of usable components of hazardous waste. Significantly, it was agreed that the definition of waste minimization will not extend to "closed loop" recycling, a process in which hazardous wastes are reused directly in the manufacture of a product.

Over EPA objections, state officials also agreed that all on-site treatment facilities permitted under the Clean Water Act and not subject to a permit under the Resource Conservation and Recovery Act will not be counted as part of a state's disposal capacity.

Similarly, hazardous wastes sent to on-site facilities regulated under the National Pollutant Discharge Elimination System should not count toward waste-minimization goals, an NGA working group said.

"Waste entering on-site processes [that are exempt from RCRA permits] should not be reported for purposes of compliance with SARA," the work group said in a report of its activities. "All other RCRA-regulated waste streams and nonregulated wastes that consume capacity at all RCRA facilities should be reported."

(Continued)

GOVERNORS DRAW UP CAPACITY GUIDELINES (Continued)

But an official said the agency has not decided whether to consider on-site, non-RCRA facilities to be outside the required capacity certification. "That issue is still on the table," he added. "Obviously EPA has to review this and approve it, and that issue has not been resolved internally. We have the final say on the whole package."

The issue involves only privately owned on-site facilities regulated under the NPDES program, not publicly owned treatment works. "It's a lot of capacity, but it's not critical capacity," the EPA official added.

Limits on Interstate Shipments Debated

Another issue that concerns EPA as the certification deadline nears is the recent tendency by some states to limit (through indirect means) the interstate movement of hazardous wastes. Barred by the Constitution from imposing outright bans on interstate commerce, some states have imposed higher disposal fees on wastes from other states or passed laws limiting the expansion of exisitng commercial disposal capacity. "It is not clear to what degree states are allowed to restrict capacity development," said an NGA task force on interstate waste issues.

It recommended that every state agree not to interrupt "current waste import-export market patterns" by declining to enact laws that would interfere with interstate waste shipments. States that establish "unreasonable export practices" by sending large amounts of their wastes to other states would be subject to EPA mediation efforts. But receiving states could eventually establish "more restrictive actions" on imported wastes "from states found to place unreasonable reliance on out-of-state facilities."

At the same time state officials agreed that they are more concerned about constitutional problems with the interstate shipment of hazardous wastes than about running afoul of the RCRA requirement for hazardous-waste programs that are consistent with the federal program. EPA has told the states they face the possible loss of their RCRA authorization if they adopt inconsistent programs, including (in some cases) requirements that are more stringent than federal standards.

A state's capacity assurances should include only disposal capacity available within the state, not capacity outside the state, the task force said. "Estimates of exports would not require certification of available out-of-state capacity, but states should indicate where they plan to direct exports," the NGA report continued. "EPA should act as a referee for export projections submitted in [1989], doing a mass-balance computation and flagging potential problems."

No Sanctions for 'Good Faith Effort'

State officials also are recommending to EPA that the federal government not punish states that do not have enough capacity by October 1989 to take care of their waste needs for the next 20 years. Sanctions (forfeiture of Superfund money) should not be imposed "so long as a good-faith effort was being made" to provide the needed capacity.

But officials ducked a decision on what to do about states that set capacity goals and fall short and on how to measure a state's need. "Consensus was not reached on when and how sanctions would be invoked if [capacity] milestones were not achieved and capacity fell short of need thereafter. The concept of judging capacity achievement in stages was accepted, but guidelines for judging adequacy were not specified," the task force report said.

TEXAS PANEL SUGGESTS ALLOWING WASTE IMPORT BANS UNDER RCRA

Citing the Low-Level Radioactive Waste Policy Act as a model, the Texas Water Commission has suggested that Congress amend the Resource Conservation and Recovery Act to authorize states to ban the import of toxic wastes that originate in other states.

"In order to effectively prevent waste imports, federal legislation will be necessary," the commission said in a recent report to Gov. William Clements. The low-level radioactive waste law, it added, "serves as a model for granting states the right to eventually ban imports to their states and charging out-of-state generators dramatically higher disposal fees until the ban goes into effect."

Groups of states acting jointly through regional low-level waste compacts can restrict disposal of low-level waste to compact members. Texas has chosen not to join a compact with other states, preferring to go it alone.

"Texas may want to consider building additional publicly owned facilities which won't accept out-of-state wastes while taking care of the needs of its own industries," the TWC report continued. "The state may also want to create special districts to handle all wastes in that district while banning imports."

It noted, however, that either course of action could endanger federal funding of the Texas hazardous-waste program under RCRA, which authorizes states to adminster hazardous-waste management programs provided they are "consistent with the federal program and other state programs."

EPA Opposes Limits on Interstate Waste Shipments

The Environmental Protection Agency, which takes a dim view of state laws restricting the interstate movement of hazardous wastes, says it will withdraw RCRA authorization for states that curb waste shipments. In addition, the agency said the laws could result in a loss of Superfund money for cleanups at National Priorities List sites.

The 1986 Superfund amendments require every state to certify to EPA by October 1989 that they have adequate capacity somewhere in the United States to dispose of all hazardous wastes generated within the state through 2009. Laws restricting waste shipments could prevent states from entering into cooperative agreements similar to those established under the low-level act to help manage hazardous wastes (see related story, p. 145).

Meanwhile, a Texas Task Force on Waste Management Policy has begun holding hearings that will culminate in changes in state laws being recommended to the legislature next year. The 20-member task force has two subcommittees -- one specializing in hazardous and industrial waste, the other in solid and infectious waste.

The panel will examine state policies that affect the siting of hazardous- and solid-waste treatment, storage and disposal facilities. The hearings began in January and will continue into the summer.

Almost 65 million tons of hazardous wastes -- 21 percent of the total nationwide -- are generated in Texas each year. Wastes that are not shipped to other states for disposal are landfilled, incinerated or injected into deep wells. The greatest environmental problems have come from old leaking landfills, the TWC says. There are 10 commercial facilities in Texas that are exclusively in the hazardous-waste disposal business. Seven new commercial facilities have been formally proposed, and another is planned.

EPA MAY TIE FACILITY SITING ISSUE TO SUPERFUND CAPACITY CERTIFICATION

To deal consistently with states that close their borders to hazardous-waste treatment facilities, the Environmental Protection Agency may politely remind state officials of their obligations under Superfund to prove they have enough waste-disposal capacity within their borders. States that fail to certify to EPA by October 1989 that they have enough capacity to manage all hazardous wastes which they produce over the next 20 years face the possible loss of Superfund financing for waste-site cleanups.

EPA officials lean toward simply holding a dialogue with the states about the fallout from erecting barriers to hazardous-waste treatment facilities, hoping they will not follow the North Carolina example and pass siting bans. Legal and policy issues raised by North Carolina's law are being examined by an agency task force that will make recommendations to Administrator Lee Thomas for a national policy. The task force could have a recommendation to Thomas by mid-May, say EPA sources.

The issue of state barriers to the interstate movement of hazardous wastes and their impact on Superfund is being examined by task forces from the National Governors' Association, which hope to submit draft guidelines to EPA next month (HWN, April 11, p. 145).

The talks with state officials would entail "explaining to states it's not in their interest to close their borders [to treatment facilities]," an agency source said. "Using the [Superfund capacity] certification process does not mean threatening the withdrawal of money." But enacting facility siting bans "jeopardizes their ability under the Superfund law to certify that they have a place to take their waste," the official added. And without that certification, states risk losing Superfund money.

While the dialogue on the Superfund certification process seems to be the most likely option, officials are looking at other ways of handling state siting bans. A second option would be for EPA to maintain that the state law is pre-empted by the Resource Conservation and Recovery Act. "We'd have to make the legal case that it was," an EPA source explained. The matter is being studied by the Office of General Counsel. While the agency would not withdraw state RCRA authority under that option, it would force waste generators to support EPA and encourage industry to seek a court judgment against the state.

To date, with the exception of objections from the waste-treatment industry and a few facility owners, the state siting ban issue has failed to stir protest from the generators themselves. "There was a firestorm when we went forward with North Carolina," one agency source explained, referring to EPA's plans to withdraw RCRA authorization in that state. The furor subsided, so that there is little impetus for the agency to go to court now on the grounds of RCRA pre-emption. "Why should we take on these battles when no one is pushing us to? If industry comes in with outrage, and states come in and say that they want EPA to be doing something like this [establishing RCRA's pre-emption over state laws], then we could change our mind," the source said.

Meanwhile, the agency still believes it can retaliate against state waste siting bans by withdrawing the state's RCRA authorization. "It's clearly an option," the EPA official added.

The issue is before the Senate Environment Committee, which is looking into constitutional questions related to proper state and federal powers. The committee has requested documents that the agency used in taking its action against North Carolina (HWN, Jan. 25, p. 37).

END

SOUTHEASTERN, NORTHWESTERN STATES
EYE REGIONAL TOXIC WASTE STRATEGIES

With the help of Environmental Protection Agency officials in Regions 4 and 10, environmental officials in southeastern and northwestern states are taking the lead in planning regional approaches to hazardous-waste management.

A Southeastern Hazardous Waste Roundtable, formed a year ago, is now charting ways for the eight states in Region 4 "to share equally in hazardous-waste management," agency official Frank Redmond said. The roundtable has organized three committees that are focusing on developing adequate disposal capacity, minimizing waste generation and starting public-information programs.

The region encompasses Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee.

Meanwhile, Region 10 Administrator Robie Russell and the chief environmental officials in Alaska, Idaho, Oregon and Washington state have jointly recommended forming a Northwest Regional Hazardous Waste Advisory Council to give "an overall focus to efforts for systematically managing hazardous wastes."

"As of now," Russell said, "there is no fixed mechanism in place to provide an overall focus for assembling the elements needed for such a system."

The 1986 Superfund Amendments and Reauthorization Act provided the impetus for the Southeastern Hazardous Waste Roundtable, Redmond said. SARA requires all states to assure EPA by October 1989 that they have adequate capacity to treat or dispose of hazardous wastes generated within their borders for the next 20 years or risk losing Superfund money.

EPA Region 4 set up the roundtable so that various groups in the southeast could discuss such issues as where hazardous-waste landfills and incinerators needed to meet SARA requirements should be located, he added. The charter members, in addition to EPA and the eight states, included the Tennessee Valley Authority, the Department of Energy's Oak Ridge Office, the Army Corps of Engineers, the Southern States Energy Board, the Electric Power Research Institute and the Hazardous Waste Treatment Council.

The roundtable has held several meetings since early 1987, when Gov. Joe Frank Harris of Georgia gave the opening address, which was attended primarily by the directors of state environmental agencies in the South.

As a result of the discussions, Redmond said, "we've got everybody talking on a regional basis." The discussions have led participants to decide that "what we want to do in Region 4 is to share the risk of hazardous-waste management," rather than have each state go it alone, he added. For example, Redmond suggested, one state might build an incinerator and another a landfill, rather than two states doing both.

The proposal to create the Northwest Regional Hazardous Waste Advisory Council was among four recommendations contained in a report that EPA released March 28. The recommendations were sent to the governor of each state.

The governors and Russell would appoint the council members, who "should assure that attention is given to the goal of developing a comprehensive regional waste management system where practicable," the report said. Other council functions would include promoting waste-reduction programs and helping Alaska, Idaho, Oregon and Washington to develop the adequate treatment and

(Continued)

EPA, STATES CREATE REGIONAL COUNCILS (Continued)

disposal capacity mandated by SARA. EPA hopes the council will be in operation by June, an agency spokesman said.

"The movement of hazardous wastes does not respect state boundaries," said Fred Hansen, director of the Oregon Department of Environmental Quality. He and Russell co-chaired the committee that prepared the report.

Of the 228,000 tons of hazardous wastes generated in Alaska, Idaho, Oregon and Washington in 1985, the report said, almost 40 percent was disposed of in a northwestern state other than the one where the wastes originated. Oregon, for example, exported 5,500 tons of wastes to Washington that year, while importing 62,000 tons from Washington.

Washington has 623 major generators, who produced 198,000 tons of hazardous wastes in 1985, the largest amount in the region. It was followed by Oregon, with 206 generators and 27,000 tons; Idaho, 30 generators, 2,000 tons; and Alaska, 23 generators, 1,600 tons.

The report also recommended that:

-- Waste-reduction programs be initiated at the federal, state and local level. "Industry should be involved in these program development efforts, and should work with regulatory agencies to assure the fullest integration of waste reduction activities into ongoing pollution-control efforts," the report said, adding that "all parties should provide education to the public on the benefits of and limits to waste reduction."

-- Additional data analysis should be done "to refine our understanding of the Pacific Northwest hazardous waste stream." Such analysis "should enable the states to estimate reliably their treatment and disposal capacity needs, and to characterize the waste streams that are amenable to waste reduction."

-- Hazardous-waste data collection systems should be developed in a way that produces compatible information among the states. "This would enable states to report and analyze information in a more consistent fashion, yielding useful information about the nature, movement and disposition of Pacific Northwest wastes, without unduly burdening industry."

DUKAKIS NAMES 'ENVIRONMENTAL ADVOCATE'
TO HEAD POLLUTION CONTROL AGENCY

Daniel Greenbaum, vice president of the Massachusetts Audubon Society, has been named commissioner of the Massachusetts Department of Environmental Quality Engineering, the state's lead agency in combatting air and water pollution and cleaning up hazardous waste sites, Gov. Michael Dukakis announced. Greenbaum took office May 1.

"Dan's background as an experienced environmental advocate and manager made him a good choice to take over DEQE," said James Hoyte, the Dukakis administration's environmental secretary. "His work ... for Audubon will enable him to tackle the wide range of issues he'll confront in his new post."

Greenbaum will succeed S. Russell Sylva. The department has a $47 million annual budget and 850 employees. It plans to hire several hundred more employees, who will be assigned to hazardous-waste cleanups. A commission headed by former U.S. Sen. Paul Tsongas is reviewing all environmental programs in Massachusetts and may recommend restructuring DEQE. The commission is expected to release a draft report this week.

MINNESOTA PANEL RECOMMENDS WASTE FACILITY DEVELOPER

The Minnesota Waste Management Board staff has recommended that a team made up of California-based IT Corp. and Chem-Security Limited of Canada build and operate a state-owned stabilization and containment facility for hazardous industrial waste. The agency's citizen board will decide soon whether to approve a tentative agreement that the staff negotiated with IT-CSL for developing the $15 million to $20 million plant. A site has not been chosen.

The staff also had been negotiating with a second team, Aptus, made up of what was formerly National Electric Inc. of Lakeville, Minn., and a subsidiary of Pittsburgh-based Westinghouse Corp.

"IT-CSL is a financially stable team that can offer Minnesota a great deal of waste management experience," said Terri Port, the board's hazardous and industrial waste programs director. "During the negotiation process, they were very responsive to our requests and concerns, particularly in regard to environmental protection."

IT, which owns and operates hazardous-waste disposal facilities in Louisiana and California, plans to sell or close its California facilities as part of a corporate restructuring program emphasizing waste treatment instead of disposal. The new corporate policy "fits in well with Minnesota's emphasis on waste reduction, recycling and treatment as the preferred alternatives to disposal," Port said. CSL operates the Alberta Special Waste Treatment Centre in Swan Hills.

The state legislature recently passed a bill authorizing the state to be the facility's sole owner or co-owner, but not the operator. Gov. Rudy Perpich is expected to sign the bill.

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ALABAMA GOVERNOR SIGNS LAW TO BAR NEW WASTE FACILITIES

A law to prohibit construction of commercial hazardous-waste facilities in Alabama after Dec. 31, 1988, unless expressly approved by the legislature, has been signed by Gov. Guy Hunt. The bill passed the House in late March after clearing the Senate in February.

State Sen. Jim Bennett, who introduced several toxic-waste-control bills this year, said he is concerned that the amount of wastes treated and disposed of in Alabama may cause health and safety risks. "About 85 percent comes from out of state, and we want to decrease it some," Bennett added.

The new law was drafted by state Attorney General Donald Siegelman after a federal court ruled that an earlier law banning out-of-state wastes violated the U.S. Constitution. The court said the first law did not establish standards for the legislature to use in deciding to reject a company's application to locate a hazardous-waste facility in Alabama.

The challenge was brought by Houston-based Browning-Ferris Industries Inc., which has been trying for several years to build a facility in Alabama. The only commercial hazardous-waste site now in operation in the state is the one at Emelle -- one of the largest in the country -- operated by Chemical Waste Management Inc. of Oak Brook, Ill.

Siting Criteria Established

The new legislation establishes seven criteria for companies to meet in siting a facility. In addition, the facility proposal must be reviewed by the joint legislative oversight committee on chemical and toxic wastes, which would make a recommendation to both houses.

Other criteria are an assessment of whether the state needs any more hazardous-waste facilities, and what effects a proposed facility would have on roads, water supplies, property values and public health and safety in the area where it is built.

Another Bennett bill aims to promote recycling and waste minimization by limiting the quantity of hazardous wastes that can be sent to commercial treatment, storage or disposal facilities annually to the 400,000 tons that were handled in 1987. The measure also would authorize the Alabama Department of Environmental Management to impose monthly limits on hazardous waste accepted at each commercial facility. That bill is awaiting Senate action.

Bennett's third waste-control bill would create a $5 million state fund to be used primarily to clean up inactive or abandoned sites that are unlikely to qualify for federal money under Superfund. To finance the state cleanup program, a fee of $6 a ton would be levied on in-state waste; the fee for out-of-state waste would be $8 a ton.

The extra $2 charge would "compensate the state for additional monitoring and enforcement expenses that result from the importing of hazardous waste into Alabama," the bill states. It is before the Senate Economic Affairs Committee.

Hunt also has proposed a bill to create a cleanup fund, ban new commercial facilities and freeze waste volumes disposed of in 1988 at last year's level. Unlike Bennett's bills, the governor's proposal calls for reducing the amount of waste sent to commercial facilities by five percent each year, starting in 1989, until the annual total is no more than 200,000 tons.

END

Volume

2

MANITOBA HAZARDOUS WASTE MANAGEMENT CORPORATION
SYSTEM SCOPE AND TECHNOLOGY STUDY
PART II - TECHNOLOGY REVIEW

Prepared by

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October, 1988

Project No. 61087

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October 25, 1988

Manitoba Hazardous Waste Management Corporation
226 - 530 Century Street
WINNIPEG, Manitoba
R3H 0Y4

Attention: Mr. J. McCabe, P. Eng.
Senior Project Engineer

Dear Sirs:

RE: System Scope and Technology Study
Part II - Technology Review

We are pleased to present herewith our Final Report on Part II - Technology Review.

We wish to express our sincere appreciation for the guidance and advice provided by yourself and your colleagues during the course of this study.

Yours truly,

D. Taniguchi

D.J. Taniguchi, P. Eng.
Project Manager

DJT:mr

Encl.

ABSTRACT

The Manitoba Hazardous Waste Management Corporation has a mandate to provide a comprehensive, environmentally sound, and cost effective system for the management of hazardous wastes in the Province of Manitoba.

This report documents Part II of a three part study. In Part II, a comprehensive review of available and emerging technologies has been carried out. Technologies for waste reduction and materials recovery, storage and transfer facilities, thermal destruction, physical/chemical treatment, immobilization and residue disposal have been reviewed. In the final Chapter of the report, the technologies that would be suitable for Manitoba have been identified by developing and applying criteria to rank each technology. Appendix A of the report includes a list of manufacturers and suppliers of the various technologies reviewed.

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CHAPTER 1.0

INTRODUCTION

CHAPTER 1.0
INTRODUCTION

The Manitoba Hazardous Waste Management Corporation has a mandate to provide a comprehensive, environmentally sound, and cost effective system for the management of hazardous wastes in the Province of Manitoba.

Reid Crowther & Partners Limited, in association with B&V Waste Management, Inc., were retained by the Corporation to carry out a three part study. The first part involved the review and critique of the Corporation's system development strategy. The second involved a review of candidate technologies to be incorporated into the system, and the third part provided a conceptual description of the required facilities.

This report documents the work carried out in Part II, the Technology Review, which involved a comprehensive overview of available technologies including waste reduction and recycling, storage and transfer methods, thermal destruction, physical/chemical treatment, immobilization, and residue disposal. In addition, identification of those technologies which would be suitable to Manitoba has been made.

CHAPTER 2.0

WASTE REDUCTION AND MATERIALS RECOVERY

CHAPTER 2.0
WASTE REDUCTION AND MATERIALS RECOVERY

INTRODUCTION

Reducing or eliminating the production of wastes is the most desirable approach to waste management because it provides the most protection to the environment. Materials recovery is the next best alternative to consider after options for waste reduction have been exhausted.

Described in this Chapter are the barriers to waste reduction and recycling, the use of the waste audit to implement a waste reduction program, followed by examples of waste reduction and materials recovery methods for various types of wastes.

BARRIERS TO WASTE REDUCTION AND MATERIALS RECOVERY

As waste treatment and disposal become more difficult and costly, and environmental regulations become more stringent, waste generators will be encouraged to seek out waste reduction and recycling measures. The liability associated with hazardous wastes will also encourage reduction and recycling. With continuing increases in the costs of raw materials, manufacturers will find economic incentive to recover materials from their waste streams.

Despite the foregoing incentives that favour waste reduction and waste recycling, certain barriers will have to be overcome as described in the following paragraphs.

In the past, waste generators have put their energy and resources into treatment of hazardous wastes in response to environmental regulations. As a result, waste generators have developed an end-of-pipe mentality, and there is a certain amount of organizational inertia which will have to be reversed.

Waste generators are normally companies which have a primary mandate of being profitable. Therefore, waste reduction and materials recovery methods will have to provide a return on investment over a relatively short period of time (usually about three years). This will limit the economical viability of some waste reduction and recycling options.

Waste generators have in the past invested in waste treatment systems. There may be an unwillingness to abandon existing waste treatment systems in favor of waste reduction or materials recovery operations until past investments have reached their planned life span.

Small and medium sized waste generators will generally not have the financial resources and technically qualified personnel to examine waste reduction and recycling options in a formal way. Waste volumes generated by the individual firm are often small. Therefore, due to lack of economy of scale, waste reduction and recyling is relatively expensive. Vehicles to promote and implement systems for groups of small generators would be beneficial in reducing costs. Examples are waste exchanges and waste management co-operatives. Technical assistance programs sponsored by government and the waste management industry would help small and medium sized generators in overcoming deficiencies in technical resources.

Small and medium sized generators may not be aware of the benefits to be derived from waste reduction and materials recovery. As part of the technical assistance program noted above, information programs sponsored by the government would assist in overcoming this barrier.

A final barrier to waste reduction and materials recovery at the generator's site is the natural desire of the generator to want to transfer to another party what is perceived to be a controversial problem.

WASTE AUDITS

Waste reduction at the source can be accomplished through three areas as summarized in the following:

Input-material Alteration	Technology Alteration	Procedural or Institutional Changes
• Material purification • Material substitution	• Process changes • Equipment, piping or layout changes • Additional automation • Changes in operational settings • Energy conservation • Water conservation	• Procedural measures • Loss prevention • Personnel practices • Wastestream segregation • Material-handling improvements

(After: Fromm, C.H. et. al., 1987) (1)

In order for waste reduction possibilities to be identified and implemented in an efficient and cost-effective manner, an organized approach is required. A waste audit provides an efficient approach for assessing waste reduction possibilities. A program based on the use of a waste audit is described below:

Step	Elements
1. Initiation	Secure commitment and authority Define goals Establish organization
2. Pre-audit	Prepare "needs" list and inspection agenda Hold pre-audit meeting and inspection Compile data and select target wastestreams
3. Audit	Inspect plant Generate a comprehensive list of waste-minimization options Evaluate options (separately by audit team and plant personnel) Select options for further analysis
4. Post-audit	Conduct technical and economic feasibilty studies

Step	Elements
5. Recommendation	Suggest preferred options
6. Implementation	Design, procure and construct preferred options Start-up Monitor performance

(After: Fromm, C.H. et. al., 1987) (1)

The successful completion of such a program requires commitment from the management of the organization. In a large organization with a basis of technical expertise, the audit can be carried out by an internal taskforce. The taskforce would include representatives from management, technical staff and operating staff. Small or medium sized generators who do not have the in-house resources can contract with waste minimization consultants for these services. The Ontario Waste Management Corporation has published an Industrial Waste Audit and Reduction Manual (2) which provides a more detailed description of the use of a waste audit program.

SOLVENT WASTES

Organic solvents are used in a variety of industries, such as paint manufacturing, petroleum refining, plastics manufacturing, pharmaceuticals, dry cleaning, auto repair and printing, to name a few. In many of these cases, the solvents become contaminated through use and must be disposed. Recycling allows the reuse of solvents, thereby reducing the volume of wastes requiring treatment and disposal.

The organic solvents which can be recovered are broadly categorized as follows:

1. Halogenated hydrocarbons (including fluorocarbons, methylene chloride, perchloroethylene, trichloroethylene and 1,1,1 - trichloroethane).
2. Hydrocarbons (including hexane, benzene, toluene, xylene, cyclohexane, ethers, mineral spirits, and naphthas).
3. Ketones (including acetone, methyl ethyl ketone, methyl isobutyl ketone, and cyclohexanone).

4. Alcohols (including methanol, ethanol, isopropanol, butyl alcohol, and amyl alcohol).

5. Esters (including amyl acetates, butyl acetates and ethyl acetates).

Waste solvents will be either in the form of a liquid (low solids content, i.e. about 1% or less), sludge (medium to high solids content) or a mixture of water and liquid and/or sludge.

If the waste consists of two liquid phases, a phase separation technique can be used to remove the undissolved organic phase, which can then be re-used. Phase separation techniques that are applicable are sedimentation, flotation, filtration and centrifugation. Solids can also be separated at this point using sedimentation or flotation.

Where the raw waste is a mixture of water and solvent, the aqueous portion can be separated using a phase separation technique and then undergo further treatment for recovery of the dissolved solvents. Solvent recovery techniques that are applicable are distillation, carbon adsorption, steam stripping and evaporation.

Where the waste stream contains a high percentage of liquid organics, solids removal alone may be sufficient to render the waste reuseable. An example is where the reclaimed solvent will be used for degreasing. If a purer product is required, the undesirable organic constituents will have to be removed. Normally, this will be the case if the reclaimed solvent is to be used as a raw material in a manufacturing process. Again, solvent recovery processes such as distillation, carbon adsorption, steam stripping and evaporation can be applied to yield a purer product.

Solvent sludges, such as the sludges produced by the previously mentioned solvent reclamation processes, can be incinerated or used as an auxiliary fuel in cement kilns and industrial boilers.

The solvent recovery techniques which were listed previously, are described in the following paragraphs.

TABLE 2-1: Capital Costs
Simple Distillation Units

Distillate Output (litres per hour)	Approximate Capital Cost *
20 to 40	$13,000
30 to 60	$17,000
40 to 80	$25,000
55 to 90	$46,000

* Cost includes equipment supply only.

Distillation

The usual process employed for solvent recovery is distillation. There are various forms of distillation which can be implemented, depending on the degree of purity required and nature of the solvent waste stream.

Single Equilibrium Stage Distillation

The simplest form of solvent distillation is a single equilibrium stage operation operated on either a batch basis or continuous basis. In this process, the waste stream is fed to a heated still pot where it is boiled, and vapours are collected and condensed. The heat source can be a steam jacket or a heating coil. The distillate will be a blend of the solvents contained in the waste.

Single equilibrium stage distillation units are commercially available in a range of sizes. These units can be used to recover solvents with boiling points ranging from 40°C to 160°C. They will be adequate when a solvent blend, rather than a pure solvent is acceptable, such as in the case of recycling solvents for use in equipment cleaning.

One manufacturer, the Finish Company, Inc., offers a batch distillation unit with a vacuum attachment which allows recovery of solvents with boiling points in the 160°C to 260°C range.(3)

Typical capital costs of commercially available package or skid-mounted units are given in Table 2.1. Installation requirements are usually minimal as the units normally require only a power supply connection in the case of electrically heated units. The room which the unit is placed in should be equipped with explosion-proof electrical devices and adequate ventilation. Containers should be grounded to prevent sparking.

Fractional Distillation

When high purity solvent recovery is required, fractional distillation (also known as multi-stage distillation, fractionation, or rectification) can be

employed. The simple distillation process described previously uses only one equilibrium between the liquid and gas phases. In fractional distillation, a series of liquid-vapour equilibria are created in a vertical column to provide a progressively higher concentration of the more volatile components in the upper sections of the column. Waste is fed to the middle of the column. A portion of the condensed stream (known as the reflux) is fed back to the top of the tower as a source of liquid for counter-current contacting of the vapours rising up the column, yielding higher concentrations of high volatiles in the overhead vapour. The reflux stream scrubs the less volatile components from the vapour phase and at the same time, the reflux stream is stripped of a portion of its more volatile content by the rising vapours. Liquid which reaches the base of the column is reboiled, with the vapour fed to the base of the tower.

The solids content of the waste to be treated must be limited to prevent clogging of the column or the coils in the reboiler.

Fractional distillation units are normally custom designed for the particular application. Costs of this equipment must be determined on a case by case basis.

Carbon Adsorption

Carbon adsorption can be used for solvent recovery from both solvent laden air streams and dilute aqueous streams. Solvents adsorbed on the carbon can be reclaimed (desorbed) by stripping with low pressure steam, washing with a solvent that will remove the adsorbate, acidic or caustic washing, or nitrogen purging.

The most economical method of reclaiming the adsorbed solvent is steam stripping, followed by distillation of the waste liquid to recover the solvent fraction.

For aqueous waste streams, pretreatment may be required to reduce suspended solids contents to less than 50 mg/litre in order to prevent carbon fouling. Also, oil and grease content must be less than 1.0 mg/litre. For aqueous

waste streams, bench-scale tests will be required in order to define design parameters since adsorption efficiency is highly dependent on the waste stream characteristics.

Union Carbide's Purasiv HR System uses a continuous fluidized bed of tiny spheres of activated carbon. Separate sections are provided for adsorption and desorption. Nitrogen or steam is used for stripping the adsorbed solvent. The system has been used to recover ketones, tetrahydrofuren, toluene, acetone and isopropyl alcohol.(4)

Activated carbon systems must be custom designed for the specific application. Costs will depend on the nature of the waste stream.

Steam Stripping

Steam stripping involves the injection of low pressure steam into the waste mixture to drive off the volatile fraction. The steam heats and mixes the waste to promote evaporation of the more volatile components.

The condensate from a steam stripper is further treated to remove the solvent component from the water. The water is then fed back to the stripper for further processing.

A disadvantage of the steam stripping process is that the wastewater which is generated may contain water soluble volatile organics, and further treatment of the wastewater will be required prior to disposal. Therefore, steam stripping is most suitable to waste liquids containing organics with low water solubilities. If highly volatile constituents are exhausted in the process, further scrubbing or incineration of the emissions may be required.

Steam stripping units must be custom designed for each particular application, with costs being dependant on the complexity and degree of treatment required.

TABLE 2-2: Agitated Thin Film Evaporators
Typical Design and Operating Data

Liquid Throughput:	Up to 900 to 1100 kg/m^2
Vessel Size:	0.1 to 40 m^2 of heated surface
Organics Distillation Capacity:	Steam heated - 63 kW/m^2 (20,000 btu/h $ft.^2$) Hot oil heated - 25 kW/m^2 (8,000 bth/h $ft.^2$)
Overhead to bottoms split:	Up to 100 to 1
Product Viscosities:	Up to 10,000 cp. at operating conditions
Blade Tip Speed:	Non-scraping blades - 9 to 12 m/sec. Scraping blades - 1.5 to 3 m/sec.
Clearance Between Wipe & Wall:	Less than 2.5 mm

(Source: Blaney, B.L., 1986)

Evaporation

Evaporation can be carried out in a number of configurations; the most common for the solvent recycling being the agitated thin-film process. In this process, the evaporation of the more volatile constituents of the waste is enhanced by spreading the waste over a large surface area. The evaporator consists of a vertical cylinder or tapered tube. Waste is spread on the interior walls of the vessel by a wiper blade assembly. A heated outer shell is used to raise the temperature of the waste to enhance evaporation. As the waste liquid flows down the walls of the evaporator, vaporization of the more volatile fractions takes place.

The wiper blades create turbulence in the liquid which increases the transfer of heat to the liquid, and promotes movement of the volatiles to the surface of the waste, thus promoting evaporation. When handling viscous wastes or wastes containing solids, the wiper blades serve to maintain a uniform film thickness and even flow of liquid.

Typical design and operating data for agitated thin-film evaporators are given in Table 2-2.

Agitated thin-film evaporators commonly are used as the first step in the recycling of solvent wastes with recoverable organic contents of 60 to 70 percent.(5) The overhead fraction can be further purified by distillation and water extraction. The bottoms typically are sold as a supplemental fuel or could be incinerated.

Liquid wastes with viscosities of up to 10,000 centipoise can be treated in agitated thin-film evaporators. Low solids content sludges can also be treated, however solids particle size would be limited to the clearance between the wiper blades and the walls of the vessel. Any wastes that will react at the design operating temperature cannot be treated.

Evaporation units must be custom designed for each application, and costs will depend on the complexity and degree of treatment required.

TABLE 2.3: Industries which Produce Metal Bearing Waste (6)

SIC Description	SIC Code
Plating and polishing	3471
Paints and allied products	2851
Metal coating and allied products	3479
Motor vehicle parts and accessories	3714
Industrial inorganic chemicals	2819
Metals, nonferrous, secondary	3341
Fabricated metal products	3400
Motors and generators	3721
Misc. manufacturing industries	3900
Metal, nonferrous, rolling, drawing	3356
Blast furnaces, steel mills	3312
Foundries, gray iron	3321
Electric services	4911
Industiral organic chemicals	2869
Plastics material	2821
Radio and TV communication equipment	3662
Electronic components	3679
Motor vehicle bodies	3711
Machine tool accessories	3545

Solvent Recycling Contractors

A Winnipeg company named Solvit has recently started a solvent recycling service. They presently charge generators approximately $1.00 per litre for cleaning waste solvents. For large quantities, collection and delivery charges may be waived. Solvit can be contacted by phone no. (204)233-0731.

Another company named Technisol of Raymond, Alberta is offering a similar service to Alberta waste generators. Technisol collects waste solvents from various generators, cleans the solvents using a single stage distillation process and sells the reclaimed solvents back to the generators. Technisol has tentative plans to collect wastes from generators in Manitoba for shipment to their Alberta plant. Technisol can be reached at phone no. (403) 752-4531.

METAL BEARING WASTES

Industries which typically produce metal bearing wastes are listed in Table 2-3. The metal finishing industries are responsible for producing a large portion of the metal bearing wastes generated.

Waste streams produced in the metal finishing industries can be divided into four general categories as follows:

- Wastewater - the major source is from the rinsing steps between various process baths. Other sources include process solution spills, scrubber water, paint booth wastewater, leaks, and cleanup wastes.
- Spent Process Solutions - Process solutions, such as plating baths, cleaners, and post-treatment baths must be disposed after reaching their useful life. Waste process solutions are also generated from spent filters, clean-out sludges, spills and leaks.
- Waste Oils - Oils are used in the metal finishing industry as metal cutting fluids, quenching oils, and lubricants. When oils become contaminated and breakdown, they must be disposed.
- Waste Solvents - Degreasing and cleaning operations are the major generator of waste solvents. Painting operations also produce waste solvents.

Treatment and destruction processes which can be applied to metal bearing wastes include precipitation, reduction, stabilization/solidification, cyanide destruction, and biological treatment. Descriptions of precipitation, reduction and stabilization/solidification are found in Chapters 5 and 6 of this document and the other listed processes are described in other literature.

Waste reduction and recovery methods for metal bearing wastes are discussed for two of the major types of metal bearing wastes - electroplating wastes and metal cutting fluids.

Electroplating Waste:

In the electroplating process, objects to be plated are passed through a series of process tanks or baths. Each bath is followed by a rinse tank which serves to remove residual process solution from the part. Waste reduction techniques for electroplating wastewaters include water conservation and drag-out reduction.

Water conservation techniques are simple and inexpensive. Any reduction in water usage in the process will result in a reduced volume of wastes to treat. Up to a 50 percent reduction in water consumption can be achieved by using properly designed rinse tanks, flow controls, countercurrent rinsing and reusing rinse water wherever possible.(7)

Drag-out is the solution which is retained on the part as it is removed from the plating process tanks. Drag-out can be reduced through operational changes such as listed in the following:

- increase part drain time
- use low pressure air to blow solution off parts
- use fog or spray rinsing over the process tank
- minimize concentrations of metal in plating bath
- rack parts to maximize drainage and design racks to maximize drainage
- use drip bars to hold racked parts over plating tank
- use maximum hole size on barrels
- rotate barrels above tank.

TABLE 2-4: Summary of Drag-Out Concentration Technologies

Technique	Advantages	Disadvantages
Electrodialysis	• Achieves higher concentration than reverse osmosis or ion exchange • Energy efficient • Organics not concentrated • Inorganic salts transport at different rates minimizes return of unwanted inorganics	• Feed must be filtered • Membrane sensitive to flow distribution, pH and suspended solids • Equipment uses multi-cell stacks, incurs leakage • Chemical adjustment of recovered material • Membrane life uncertain
Electrolytic metal recovery	• Recovers only metals • Results in saleable, non-hazardous product • Energy efficient • Low maintenance	• Solution concentration must be monitored • Fumes may form and may require hood scrubbing system • Solution heating encouraged to maximize efficiency
Evaporation	• Established and proven technology, very reliable • Simple to operate • Widely applicable • Can exceed bath concentration	• Some units are energy intensive • Multi-stage countercurrent rinsing essential • Returns bath and impurities • Additional treatment may be needed to control impurities • May require pH control
Ion exchange	• Low energy demand • Handles dilute feed • Returns metal as metal salt solution	• Requires tight operation and maintenance - equipment complex • Limited concentration ability • May require evaporation to increase concentration • Excess regenerate required • Feed concentration must be closely monitored
Reverse osmosis	• Achieves modest concentration • Small floor space requirement • Less energy intensive than evaporation	• Limited concentration range of operation • Fouling of membranes due to high suspended solids in feed; feed filtration essential • Membrane sensitive to pH • Some materials fractionally rejected • May require further concentration

It may be possible to use an alternate process bath which has a lower concentration or none of the chemical which is difficult to treat. Drag-out can be recovered by inserting a non-flowing rinse tank between the process tank and the running rinse. One or more drag-out tanks can be used. Each tank will reduce the concentration of the running rinse by 50 percent.(6)

The recovered drag-out can be recycled directly to the process tank from which it came. Prior to recycling, the drag-out can be concentrated by removing some of the water content.

Waste recovery processes can be applied to the drag-out and rinse water to recover metals from the waste or to concentrate the liquid prior to recycling to the process bath. Processes which are suitable for this application are:

- evaporation
- electrolytic metal recovery
- ion exchange
- reverse osmosis
- electrodialysis.

The advantages and disadvantages of each of these processes is given in Table 2-4, and further comments on some of the processes are given in the following:

Evaporation

Evaporators have been used successfully in the electroplating industry in the concentration of rinse waste generated in the plating process. Four types of evaporators are commonly used by the electroplating industry:

- Rising Film Evaporators
- Flash Evaporators
- Submerged Tube Evaporators
- Atmospheric Evaporators

Electrolytic Recovery

In this process, an electrical current is passed through the metal bearing waste stream between a cathode plate and an anode. The positively charged metallic ions are attracted to the cathode and are subsequently stripped and recovered. The process has been used in the past largely for recovering gold and silver, but recent advances appear to be making it more viable for less precious metals.

Research at the University of Maryland (Walters, R. et al, 1984) has indicated that zinc recovery from rinse waters was possible, using stainless steel electrodes and agitation of the liquid using either mechanical mixing or nitrogen gas aeration.

Ion Exchange

Ion exchange involves the passing of the liquid waste through a resin bed. Ionic species in the waste are exchanged with those in the resin bed and attach to the resin. When the resin bed is saturated with contaminants, it is rinsed with a brine or acid solution. The contaminants can be recovered from the rinse liquid.

Ion exchange has wide application in the metal finishing industry.

Reciprocating flow and countercurrent exchange systems appear to be capable of providing reduced capital costs, automatic regeneration of resin, and compact size.(6) Various researchers have studied the application of specific resins to particular waste types. The recent studies indicated the following results:

- Tara et al (6) found that chelating ion exchange resins provide a practical treatment process for metal wastes containing complex organics and inorganic ligands.
- Maeda (6) found that the large pore radius or macroreticular chelating resins proved beneficial in the recovery of heavy metal ions.

Liquid ion exchange has shown promise for treating dilute metal waste waters. The three-step process occurs as follows:

- Metal ion diffuses to aqueous/organic interface.

- The ion is stripped of its hydration layer and complexes with the extractant at the interface.
- The metal/organic complex diffuses into the bulk organic phase.

Reverse Osmosis

Reverse osmosis (RO) is a membrane process which can be used to recover dissolved solids from a liquid waste stream. Operating pressures are typically in the range of 2700 to 3500 kPa (400 to 500 psi). In an RO system, the waste liquid is pressurized against a semi-permeable membrane which allows the passage of water, but not the dissolved solids. RO is well suited to wastes containing ionic compounds such as heavy metal solutions resulting from rinsing operations in the electroplating industry.

Depending on the nature of the waste, the membrane can be made of a variety of materials and configurations. Typical membrane types are listed in the following:(6)

Waste Stream	Membrane Description
Nickel	- cellulose acetate
Copper Sulfate	- hollow-film polyamide - cellulose triacetate and spiral-wound thin-film composite
Zinc Sulfate	- spiral-wound thin-film composite
Brass Cyanide	- polyamide cellulose - triacetate hollow fibre
Copper Cyanide	- polyamide hollow fibre
Chromium VI	- spiral-wound thin-film composite

Typically RO units are capable of recovering 80 to 99 percent of most heavy metal contaminants in plating bath rinses. The exceptions to this are heavy metals in the anionic state such as chromate (CrO_3^{6+}) and stannate (SnO_3^{6+}) ions.(8)

To limit fouling of the membrane, the raw wastewater is often first passed through a filter (5 microns). Pilot testing is recommended before full scale implementation.

Packaged RO units are manufactured by various firms in North America, including Petwa Canada Ltd. (Calgary) and Zenon Sales Ltd. (Burlington). Typical capital costs for various sizes of unit are as follows:

Capacity (Product Water)	Estimated Cost(*)
4 litres/min.	$ 7,200
15 litres/min.	$15,200
30 litres/min.	$23,600

(*) Equipment supply only

Data from Zenon Environmental Inc.

Waste Metal Cutting Fluids:

Fluids used in metal working become contaminated through use by small particles of the metal being worked. They also become contaminated by hydraulic fluids, lubricating oils and greases which leak from the machinery into the fluid. These fluids are known as tramp oil when they have entered the cutting fluid.

The first step in a waste metal cutting fluids reduction program is a proper fluid management program. This essentially involves ensuring that the machinery is operated and maintained in order to reduce the rate of contamination as much as possible.

Once cutting fluids have been contaminated, there are various methods such as settling, filtration, hydrocycloning, centrifugation and magnetic filters, which can be applied to recover the fluids.

Settling involves allowing solids to settle by gravity out of the solution and allowing oil to rise to the surface. Settling is economical and simple, however the disadvantage is that long retention times may be required for removal of fine particles. Also, all of the tramp oil will not be removed.

TABLE 2-5: Fuel Value of Common Liquid Wastes

Black Liquor	4,400 Btu/lb.
Dirty Solvents	10,000 to 11,000 "
Spent Lubricants	10,000 to 14,000 "
Paints and Resins	6,000 to 10,000 "
Oil Waste, Fuel Oil Residue	18,000 "

(Source: Cheremisinoff, P.N., Resource Recovery: A Special Report, Pollution Engineering, November 1987) (9)

Oil removal efficiency can be increased with the use of a coalescing plate separator.

Both gravity and vacuum fabric filtration can be used to remove particles from metal cutting fluids. This involves the passing of the fluid through a material with fine holes in it to separate the solid particles from the fluid.

A hydrocyclone can be used to remove smaller particles from metal cutting fluids. The process uses centrifugal forces created by a vortex to separate the heavier solids from the fluid. Particles as small as 5 micrometres can be removed using a hydrocyclone. Hydrocyclones are relatively simple to operate and maintain, however, tramp oil removal is not affected.

Centrifugation involves the use of centrifugal force created by spinning the process fluid in a drum or bowl shaped container. Again, the centrifugal forces cause solid particles to be separated from the liquid. Particles as small as 2 micrometres can be removed and tramp oil content can be reduced to 0.5 percent. The centrifuge system is more expensive than other methods described herein, however it is able to remove the greatest amount of contaminants.

Ferrous metals can be removed from cutting fluids by using magnetic forces. Magnetic filters are capable of removing ferrous particles as small as 35 micrometres, however they will not remove tramp oil from the fluid.

LIQUID WASTE FUEL COMBUSTION

Industrial Boilers:

Many liquid wastes exhibit properties of potentially good fuels. The fuel values of some common liquid wastes are given in Table 2.5. In recent years, there has been an increase in the use of waste oils and spent solvents as auxiliary fuels for industrial boilers. Waste oils refer to used motor crankcase oils and spent machinery lubricating oils. Waste oils can

contain additives such as barium, magnesium, zinc, sulfur, nitrogen, calcium and phosphorus, and contaminants accumulated during use such as lead (from leaded gasoline), and other metals (iron, chromium, nickel, molybdenum, aluminum, zinc, and magnesium) produced during engine or machinery wear.

Spent solvents are generated by a wide variety of industries which use solvents in their processes or for cleaning and degreasing. Spent solvents can often be reclaimed by treatment (filtration, distillation, evaporation, etc.), however when they have been contaminated to the point which reclamation is not economical, use as an auxiliary fuel can provide a means of disposal. Non-halogenated solvents are preferred as waste fuels for industrial boilers since halogenated solvents are generally poor fuels and they require the use of acid gas scrubbers.

In terms of requirements for retrofitting existing industrial boilers to burn waste oils or spent solvents as auxiliary fuel, the first component requiring consideration is a liquid waste storage system at the facility. Most solvents that will be suitable for use as waste fuels are flammable liquids (flash point <100°F), whereas conventional fuel oils are combustible liquids (flash point >130°F). Therefore, the handling, storage and delivery systems must be suitably modified to provide adequate safety protection. It is preferable to locate flammable liquid storage tanks and pumping equipment outside such that if a leak occurs flammable vapours will be dispersed.

If the waste fuels contain settleable solids, a separate settling chamber or tank should be provided upstream of the storage system.

For single burner boilers designed for combination gas/oil firing, the only necessary modifications will be oil gun replumbing and minor control system changes. Liquid wastes can be fired through the centre fuel gun and natural gas or fuel oil can be fired through the outer ring to sustain the desired steam load.

An alternative is to install a mixing system to combine the waste with the usual fuel upstream of the burner nozzle. This method can be implemented if the waste is of consistent composition and the waste and fuel are miscible

and have compatible volatilities and viscosities. A third option is to replace the existing burner with one designed to co-fire liquid waste and natural gas/oil. This will provide the best long-term efficiency and minimize maintenance requirements.

If the boiler system has only one burner nozzle for co-firing the waste fuel and regular fuel simultaneously, a condition known as boiler flameout can occur. This condition results when a slug of residue or water enters the boiler burner nozzle and causes a temporary flame extinguishment. When the slug passes, raw fuel enters the boiler chamber where it may accumulate and explode. This condition can be prevented by installing the proper control system.

Cement Kilns

Solvent wastes can be used as a supplementary fuel source for rotary kilns used in the cement and aggregate manufacturing industry. The energy costs for cement and aggregate kilns represent as much as 50 percent of the facility operating costs.(10) Energy costs can be reduced by up to 15 percent through the use of solvent wastes.(11) Cement kilns typically have gas residence times of 6 to 10 seconds and operating temperatures of 1500°C, both of which are much higher than what hazardous waste incinerators are designed for.(12)

Test results compiled by the U.S. EPA (12) on various cement kilns equipped with electrostatic precipitators indicate that in most cases, little change in particulate emissions occurs when burning hazardous wastes. For example, chlorinated organic destructions of 99.99 percent or better were recorded during test burns conducted from 1974 though 1976 at the St. Lawrence Cement facility in Mississauga, Ontario. Similar results were recorded during test burns at the General Portland facility in Lebec, California (1983), the Lone Star Industries facility in Oglesby, Illinois (1983), and the Rockwell Lime facility in Manitowoc, Wisconsin (1983). In cases where particulate emissions increased, it was either due to process equipment malfunction, or high amounts of chlorine in the feed waste. Moderate amounts of chlorine do not generate a problem since the clinker product is highly alkaline and thus

scrubs the acid gases from the flue gas. It has been found that chlorine inputs of up to 6 kg per Mg of clinker do not result in increased particulate emissions.

Cement kilns typically are fuelled by a variety of fuels, including natural gas, oil, coal, waste coke and any other material of sufficient Btu value. One installation is reported to use waste sludge from the fermentation process of a distillery. Therefore most cement kilns will be capable of burning hazardous wastes in liquid or sludge form if suitable feed equipment is provided. For liquid wastes, storage tanks will be required to blend the waste fuel with the normal fuel to ensure that the fuel feed to the kiln is of a relatively constant thermal value. As the foregoing infrastructure requirements are relatively small, the capital cost of modifying an existing cement kiln to accept hazardous wastes will not be large.

To ensure that destruction and removal efficiencies are maintained within acceptable limits, emission monitoring equipment will have to be put in place.

PAINT MANUFACTURING WASTES

The paint manufacturing industry typically produces significant quantities of waste products. The highest portion of the wastes generated by the industry (13) is associated with the cleaning of paint production equipment, which results in waste rinse water, waste solvent, and paint sludge.

Waste volume reduction and waste recycling can reduce both waste treatment costs and raw material cost.

Wastes generated in cleaning operations can be recycled by using them in the next compatible batch of paint, distilling them for reuse either on site or off site, or by simply reusing them for equipment cleaning until they are too dirty for further reuse.

In the manufacture of solvent based paints, waste solvent from equipment cleaning can be recycled. The recycle loop can be equipped with a bleed to a solvent still, where volatile solvent is recovered and returned for reuse. The still bottoms can be incorporated into a subsequent product. For example, a paint manufacturer in California (13) reworks still bottoms with fresh material to produce a primer product.

In the production of water-based paints, wastewater or alkaline solutions used for equipment cleaning, can also be worked into the manufacture of subsequent products. The same California paint manufacturer uses the sludges to produce a beige-colour water-based paint.

The development and use of alternate coating materials is the ultimate method of reducing solvent wastes generated by the paint manufacturing industry. Various coatings, such as high solids, powder and radiation-cured coatings are being developed and will result in a reduction of solvent wastes.(14)

CAPITAL COSTS

In general, the waste recovery technologies reviewed in this Chapter must be custom designed to suit a specific application and costs of purchasing this equipment will depend to a large degree on the nature of the waste stream and degree of recovery required. Where packaged units are available, the estimated costs of these units have been provided based on information obtained from various manufacturers. The costs for any specific application can be determined by contacting the appropriate organizations which custom design and build the required recovery unit. A list of such organizations is included in Appendix A of this report.

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WASTE REDUCTION AND MATERIALS RECOVERY

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CHAPTER 3.0

STORAGE AND TRANSFER FACILITIES

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STORAGE AND TRANSFER FACILITIES

INTRODUCTION

In any overall system for managing hazardous wastes, storage facilities will be required at the waste source, at collection and transfer facilities, and at the treatment and disposal facilities. Transfer facilities will be required to collect, segregate, store on an interim basis, and prepare for shipment, wastes generated in a given region of the waste management system.

This chapter addresses the technical aspects of currently used storage systems. Information is also provided on the requirements for transfer stations.

ABOVE GROUND STORAGE TANKS

Above ground liquid waste storage tanks are typically constructed of carbon steel. Other materials (such as stainless steel and concrete) or special linings (such as rubber, coal-tar, and glass) should be considered depending on the corrosivity of the waste to be stored.

The following is a brief listing of requirements for above ground storage tanks:(2)

- Appropriate set back distances from property lines, right-of-ways, and buildings.
- Air venting to allow for filling and emptying and thermal expansion.
- Equipment to recover vapours and control fugitive emissions in the tank vent stream.
- Flame arrestors on vent pipes to prevent flashback into the tanks.
- Emergency relief venting.
- Proper foundations to prevent tank tipping.

TABLE 3.1: Approximate Costs for Liquid Storage Tanks (1) (above ground)

Item	Tank Capacity, litres (U.S. gal.)		
	19,000 (5,000)	38,000 (10,000)	95,000 (25,000)
Vessel, carbon steel*	$13,000	$18,000	$ 38,000
Dimple jacketing	5,000	8,000	20,000
Agitator, stainless steel	10,000	13,000	15,000
Pumps (2), stainless steel	17,000	18,000	40,000
Piping	13,000	17,000	22,000
Insulation	5,000	8,000	22,000
Grating	2,000	3,000	8,000
Diking	8,000	12,000	22,000
Total	$73,000	$97,000	$187,000

*Material of construction (applied to vessel cost)	Cost factor
Stainless steel 316	2.7
Stainless steel 304	2.4
Rubber-lined	1.7
Glass-lined	5.8

(Note: The costs given in the reference were in 1983 U.S. Dollars. They have been adjusted for inflation and converted to Canadian Dollars.)

- Equipment for warning of fire/explosion hazard and equipment for fire fighting.
- Spill containment diking sized to hold at least the volume contained by the largest tank.
- Tanks used for the storage of flammable and combustible liquids should be designed in accordance with NFPA 30 - Flammable and Combustible Liquids Code.
- If practicable, tanks should be mounted on pedestals to readily allow inspection of their bottoms for leaks.

Typical installed costs for three sizes of tanks are given in Table 3-1.

UNDERGROUND STORAGE TANKS

In general, it will be less costly to construct liquid storage facilities above ground. However, certain site constraints such as space limitations, may not allow this. This is particularly true for flammable waste storage tanks which will be subjected to clearance requirements between other above ground structures. In such cases, underground storage facilities must be considered.

Generally, underground storage tanks should be equipped with many of the features described for above ground storage tanks. The design of underground storage facilities will also require special consideration to minimize the chance of leakage, and allow immediate detection of any leakage. The current technology and design features which should be considered for incorporation into such facilities are presented in the following paragraphs.

Materials of construction must be selected to be compatible with the waste to be stored. Alternatives include, but are not limited to concrete, high density polyethylene, fibreglass, steel and stainless steel.

Recent regulations in various jurisdictions in the USA require a double containment system for underground storage of hazardous substances. This is normally provided by constructing a double-walled tank or placing a single-

walled tank within a concrete vault. In some installations, double-walled tanks have been installed in concrete vaults, providing three levels of containment.(3) As an alternate to a concrete vault, a flexible synthetic liner system can be installed.

For double-walled tanks, leak detection can be provided in the form of liquid sensors located between the primary and secondary containment systems. However, if only the secondary container fails, this will not be detected. Thus, if the primary containment system subsequently fails, a spill is likely to occur.

An improvement is to add a vacuum leak detection system which involves applying a vacuum to the space between the primary and secondary containers. A failure in the primary container will be detected by loss of vacuum if the leak is above the liquid level in the tank, or by presence of liquid if the leak is below the liquid level in the tank. A failure in the secondary containment system will be detected by loss of vacuum, or presence of groundwater.

The leak detection system should sound an alarm in an occupied space of the facility. In addition, the tank should be equipped with a liquid level sensor and high level alarm system to provide protection against accidental overfilling of the tank. A level recorder is also useful in providing a historic record of volumes of wastes generated.

Metal tanks should be provided with some mechanism of corrosion control such as cathodic protection or corrosion-resistant coatings.

Any piping leading to and from the underground storage tank should also be double-contained and equipped with leak detection equipment. Underground piping should be minimized or eliminated by locating the storage tank directly adjacent to the waste source.

STORAGE AND SHIPPING CONTAINERS

Several container types are available for storage and shipping of hazardous wastes. Container types include steel drums, polyethylene drums, and fibre drums available in sizes up to 1300 litres (350 US gallons). Plastic-lined pallet boxes and laminated cloth bags are available for bulk solid wastes. Small containers for small quantities of wastes, such as laboratory or infectious wastes are also available. Whichever container type is selected, it must be capable of withstanding the abuse anticipated during loading/unloading, handling, and transportation. For example, motorized equipment such as forklifts which are used to move containers within the storage facility, pose a particular potential for damage to the containers.

Some of the special containers which are available are described in the following paragraphs.

Drums:

All drums must meet Canadian Transport Commission specifications. Drums are manufactured of various materials and are available in a variety of sizes. The standard steel drum (55 US gal.) with a fixed top (known as tight head) is commonly used for liquids. For solid and semi-solid materials, drums with fully removable heads are available to facilitate filling and emptying.

Fibre drums are available in sizes similar to steel drums. Fibre drums offer the advantage of ease of disposal. Following use, they can be crushed and incinerated.

Drums manufactured of polyethylene are also available in a variety of sizes.

As an alternate to drums, the use of cube-shaped tanks can be considered. These are manufactured in sizes up to 1250 litres (330 US gallons). Their shape makes them easier to stack and they offer more efficient usage of space than cylindrical-shaped drums. Cube tanks manufactured by Chemical Handling Equipment Co. Inc. (Toledo, Ohio) consist of a translucent polyethylene inner tank surrounded by a metal wire enclosure. The liquid level in the tank is visible since the polyethylene is translucent. The bottom of

TABLE 3.2: Approximate Costs of Containers

TYPE	COST*
Steel Drum	$ 30 to $ 40
Fibre Drum	$ 15 to $ 25
Polyethylene Drum	$500 to $600
Steel Overpack	$ 50 to $100
Polyethylene Overpack	$150 to $300

* Costs given are based on budget prices provided by the various manufacturers and are intended to provide the reader with an indication of the costs. The manufacturers should be contacted for quotations prior to purchase.

the metal enclosure is equipped with legs to facilitate stacking and pockets to allow easy lifting by forklift. The tanks are designed to be reused, thus avoiding the problems associated with drum disposal. They can be equipped with internal sprayer fittings which facilitate flush cleaning.

Drum Overpacks:

Various manufacturers are producing containers into which leaking drums can be placed for safe handling, shipping and storage. These containers, known as overpacks or salvage drums, are made of a variety of materials including polyethylene, fibre-glass/poly composite and steel.

Typically, the containers are designed with an integral collar to allow handling by forklift. Three manufacturers which produce overpacks are Bondico Inc., Skolnik Industries Inc., and Essex Environmental Industries Inc. Polyethylene overpacks for 200 litre (55 gallons) drums cost between $150 and $300 each, depending on the material of construction with discounts available for volume purchases.(4)

Some of these containers can be fitted with "top hat" lids which allow containment of items which are taller than a normal drum, such as a transformer. The lids of the polyethylene containers can be fused to the body of the container to minimize leakage during transport.

A list of the approximate costs of the various types of drums and drum overpacks available is given in Table 3-2. A listing of container manufacturers is given in Appendix A.

Truck Containers:

Roll-off containers are now being manufactured specifically for liquid wastes. The container becomes a mobile unit which is initially placed at the waste generation site and used as a storage facility accepting wastes as they are generated. When full, the container can be picked up by a conventional roll-off truck unit and transported to the disposal site.

One manufacturer (5) (Galbreath Inc.) pressure tests their units to ensure they are leakproof. The containers can also be used to store and haul sludges, in which case large loading doors on the top of the container, and large unloading doors on the side or rear of the container are incorporated to facilitate loading and unloading.

Various companies are manfacturing custom designed bag liners to fit inside roll-off containers and dump trailers. The bag liners can be made of various grades of plastic material to allow safe transportation of solid wastes containing some liquid. For example, one manufacturer (6) (Packaging Research and Design Corp.) offers a bag liner made of 6 mil low density polyethylene that would be suitable for hauling a dewatered sludge of about 25 percent solids content. Higher quality bag liners are available for sludges of a higher liquid content.

The bag liners are normally manufactured with triple thickness in the tailgate, in the case of a dump trailer, to provide extra security because potential for tearing is greater in this area.

Bag liners also offer the advantage of reduced roll-off container/dump trailer clean-up costs at the disposal site, since the bag is disposed of with the waste hauled, eliminating the need for washwater and washwater treatment.

A typical bag liner constructed of low density polyethylene will cost in the order of $20 to $70 U.S. each (6) depending on the size and quality of materials of construction.

TRANSFER STATIONS

The purpose of a transfer station in a hazardous waste management system is to provide a facility to receive, segregate, bulk, store on an interim basis, and prepare for shipment, hazardous wastes which are to enter the system. Transfer stations will also make the waste management system more accessible to waste generators and should minimize transportation costs

since the wastes of several small generators can be shipped in a common vehicle to the treatment facilities.

During the planning stages of the system, locations for transfer stations will be selected based on further waste market characterization studies, the possible location(s) of the integrated treatment facilities and transportation costs. The types and quantities of wastes generated within the regional areas to be served by a given transfer station will dictate transfer station characteristics, such as physical size and waste segregation requirements. The desirable features of a hazardous waste transfer station which is required to handle a large volume of wastes of various characteristics are described in the following paragraphs.(7,8)

Waste Reception:

It is anticipated that a requirement of the waste management system will be that the generators will be required to make arrangements with the Corporation for acceptance and disposal of their wastes prior to shipment. This will allow the Corporation to gain knowledge of the waste and to schedule activities at the transfer station and treatment facility. Accordingly, all wastes arriving at the transfer stations will be accompanied by a manifest which will identify the waste. It will be desirable to sample and analyse the wastes arriving at the transfer station to confirm that the waste is as stated on the manifest. Therefore, suitable sampling and analytical equipment will be required at the transfer station to carryout quick checks on the characteristics of the waste.

Any wastes which are sampled and analysed, and found to be different than as described on the manifest, will have to be set aside or "quarantined" until the discrepancy can be sorted out.

The waste reception area will have to be equipped with appropriate container handling equipment. It is anticipated that most of the wastes will be liquids and sludges and will be delivered to the transfer station in standard 200 litre drums. Therefore, suitable drum unloading equipment, such as forklifts and/or crane units equipped with drum clamps will be required. A

drum deheader may be required to remove the tops of tighthead drums to remove sludges and pastes which have formed at the bottom of the drums. It will be desirable to bulk wastes which are of comparable nature to reduce handling and storage requirements. This will require suitable drum emptying equipment and bulk storage containers.

The reception area will have to have an area allocated for the examination of containers for damage and leakage. Any containers which are leaking, or which have potential for developing a leak during storage and transportation, will have to be emptied into other containers or placed into drum overpacks.

If wastes in bulk form are expected to be delivered to the transfer station, then unloading and storage equipment will be required. Equipment would include pumps and/or vacuum systems, appropriate piping and valves, and bulk storage tanks.

Waste Segregation and Storage:

The wastes will have to be segregated prior to storage. Wastes of different types will have to be stored in separate areas. Any wastes of a very toxic or otherwise dangerous nature will have to be stored in a separate enclosed area. The number of classes of wastes to be allowed for will depend on the characteristics of wastes anticipated to be generated in the regional area served by the transfer station. Sufficient separate storage areas will be required to meet fire protection requirements, worker safety considerations and transportation of dangerous goods regulations.

Features which should be considered for waste storage areas are listed in the following. The necessity of each feature should be evaluated on a case-by-case basis.

- Separate storage areas for highly toxic wastes.
- Concrete block partition walls separating storage areas from other general areas.

- Each storage area should be bermed or curbed to prevent mixing of wastes in the event of a spill.

- Each area should be equipped with a separate floor drainage system and waste collection sump. Any spilled materials, washwater, or fire sprinkler water that enters the sump will have to be treated as a hazardous waste. Therefore, provision for removing the wastes from the sumps will have to be provided.

- More than one entry/exit door. Emergency exit doors should be equipped with devices to annunciate usage.

- Storage rack layouts will have to allow for quick removal of any given container, if discovered to be leaking. For example, drummed wastes should be placed in rows of two wide with adequate aisle space between rows to allow access by forklift.

- Smoke, flame and heat detectors.

- Toxic and flammable gas detectors and ventilation equipment interlocked with the detectors and automatically activated under dangerous conditions.

- Deluge shower and eyewashes.

- Safety markings to boldly identify emergency exits.

- Fire fighting equipment designed in accordance with National Fire Protection Association (NFPA) recommendations.

- Self-contained breathing apparatus.

- Alarm system which can be activated from inside the storage area by the operator.

- Explosion relief panels or vents.

- Telephones.

- Air tight doors to prevent migration of gases from the storage area to cleaner areas.

- Explosion-proof electrical equipment.

- Chemically resistant floor finishes.

Loading Facilities:

The stored wastes will have to be prepared for shipment to the treatment facility. For drummed wastes, one option is to palletize the drums for shipment. Typically, four drums are placed on a pallet and then loaded onto

the transport vehicle. The pallets offer some protection against container damage by the handling equipment. The drums can be palletized during the segregation and storage function, or just prior to shipping. A more cumbersome alternative is to load the drums individually. This requires the use of a unit equipped with a drum clamp, which contacts the container directly, thus increasing the risk of container damage.

The Alberta Special Waste Management Facility and Chem-Security Ltd. have developed special drum containers for transporting wastes from the transfer stations to their treatment facilities. Each container is 6 metres long by 2.4 metres wide by 1.4 metres high and holds 36 standard drums. The containers are set on flatbed trailers for transportation to the treatment facilities.

Capital Costs:

The capital cost of a transfer station built to the foregoing standards will be in the order of $1100 per square metre of floor area. The cost will vary depending on which features are incorporated into the facility.

As a comparison, a basic storage warehouse for non-hazardous materials will cost in the order of $400 to $600 per square metre. The much higher costs for a transfer station are due to the safety features which must be incorporated to ensure secure storage of the waste materials.

Infrastructure Requirements:

Infrastructure requirements will vary depending on the capacity of the transfer station. Items to be considered for incorporation into the transfer station infrastructure are listed in the following:

- Operator facilities, such as toilets, shower, change room.
- Emergency electrical power supply to maintain lighting and ventilation during failures of the normal power supply.
- Service water and air.

- Surface runoff collection system.
- Site fencing.
- Yard lighting.
- Emergency spill control equipment (drum overpacks, absorbent materials, safety equipment).
- Suitable vehicle access and parking.
- Ample site space for vehicle movement and parking, and buffer area around facilities.

Small Transfer Stations:

In many cases, only small volumes of wastes and only a few types of wastes will have to be handled at a given transfer station. In these cases, all of the requirements described in the foregoing will not be necessary. The actual features to be incorporated in a given case must be carefully assessed based on a knowledge of the waste market and the functions to be carried out at the facility.

Package Transfer Stations:

Where a small amount of storage is required, an option to a custom designed site constructed facility is the factory built turnkey storage shed. One manufacturer, Safety Storage, Inc., of Cupertine, California, builds three sizes of buildings; the largest being 7 metres long by 2.7 metres wide by 2.6 metres high. The buildings are constructed of metal and can be equipped with most of the safety features required for full size facilities. The cost of the basic building is about $25,000. A fully equipped building, equipped with divider walls, insulation, heat, ventilation, fire protection equipment, and spill detection equipment will cost in the order of $75,000.

Another manufacturer, Environmental Container of Delafield, Wisconsin, offers a portable metal box shaped storage unit which holds either two or four 200 litre (55 US gal.) drums. The boxes are equipped with a latched lid, sensing alarms to warn of drum leakage, and a base designed to allow lifting by a forklift. The units could be used as an on-site storage facility by

small quantity hazardous waste generators as well as serve as secondary containment during shipment. The larger units are manufactured in Winnipeg and cost approximately $1300 each.

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STORAGE AND TRANSFER FACILITIES

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CHAPTER 4.0

THERMAL DESTRUCTION TECHNOLOGIES

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THERMAL DESTRUCTION TECHNOLOGIES

INTRODUCTION

Thermal treatment of hazardous wastes involves processes that use high temperature as a principal mechanism for waste destruction. By far the most well developed and most widely used of the thermal destruction technologies is incineration in which waste materials are oxidized at high temperature (usually greater than 900°C depending upon halogen content of the waste) in the presence of excess oxygen.

In order of popularity, the four most common incinerator designs in operation for disposal of large quantities of hazardous waste in North America are:

(1) Liquid Injection
(2) Rotary Kiln
(3) Fixed Hearth
(4) Fluidized Bed

Table 4-1 indicates the various types of wastes suited to each of the four main incinerator designs.

Other thermal destruction technologies also are applicable to hazardous wastes. Some of these include commercially available systems for dealing with remedial site cleanups, whereas others are in varying stages of development ranging from experimental to the construction and operation of one or two full-scale prototype demonstration units. These include:

- Wet Oxidation
- Supercritical Fluid Incineration
- Plasma Arc Pyrolysis
- Molten Salt Incineration
- Infrared Pyrolysis
- Joule-Melting Furnace
- Electric Pyrolizer
- Taciuk Processor

TABLE 4-1: Applicability of Major Incinerator Types to Wastes of Various Physical Forms (After Mackie & Niesen, 1984)

Form of Waste	Liquid Injection	Rotary Kiln	Fixed Hearth	Fluidized Bed
Solids:				
Granular, homogeneous		X	X	X
Irregular, bulky (pallets, etc.)		X	X	
Low melting point (tars, etc.)	X	X	X	X
Organic compounds with fusible ash constituents		X		
Unprepared, large, bulky material		X		
Gases:				
Organic vapour laden	X	X	X	X
Liquids:				
High organic strength aqueous wastes	X	X	X	X
Organic liquids	X	X	X	X
Solids/Liquids:				
Waste containing halogenated aromatic compounds	X	X	X	
Aqueous organic sludges		X		X

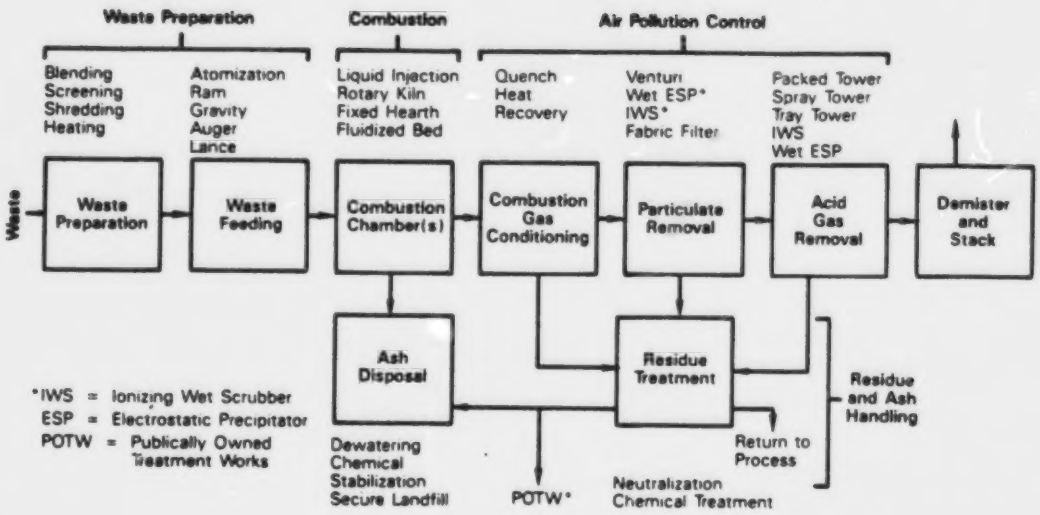


FIGURE 4-1

Subsystems in a Hazardous Waste Incinerator Train (After Oppelt, 1987)

Each of these is discussed under separate headings in this section of the report. One other type of thermal destruction system not mentioned above that is of potential significance to the Province of Manitoba is co-disposal of hazardous wastes with other fields in an industrial process. This is described under a separate heading in this section of the report.

In general, there are four major sub-systems which comprise an overall hazardous waste thermal destruction system. These sub-systems are:

- Waste Preparation and Feeding System
- Combustion Chamber(s)
- Air Pollution Control Train
- Residue/Ash Handling System

The significant components of each sub-system are illustrated in Figure 4-1.

WASTE PREPARATION AND FEEDING

Hazardous waste is produced in many forms (liquids, slurries, sludges, pastes, solids, or a combination thereof) and can be shipped in bulk or various sized containers. The purpose of the waste preparation system is to render the waste into a suitable form such that it can be handled by the incinerator feeding system and effectively destroyed in the combustion unit.

Liquid wastes commonly are blended to achieve a uniform viscosity, thermal value, water and halogen content so that steady state combustion, gas scrubbing and ash handling conditions are achieved in the overall incineration system. In general, a liquid waste usually can be pumped if its viscosity is less than 10,000 SSU and can be atomized at viscosities of up to 750 SSU (2). Thermal values of about 18,500 kJ/kg (8,000 BTU/lb) or better are preferred for liquid wastes so that the combustion flame is reliably maintained (3). Auxiliary fuel usually is required for liquids with a heating value of about 11,500 kJ/kg (5,000 BTU/lb) or less (2). Wastes with chlorine contents of 70 percent or higher can be incinerated but common operating practice is to limit chlorine content in the blended waste to 30 percent or less

(3) by means of blending with non-halogenated wastes to reduce the load on the gas scrubbing equipment.

If a liquid waste does not vaporize readily at ambient temperature, it will be difficult to ignite. In this case, some form of atomization will be required to create a large surface area to volume ratio so that the liquid can readily mix with air, vaporize and burn. Therefore the waste burners (or injectors) usually incorporate either mechanical energy, or the energy imparted by a high pressure air or steam jet, or a sonic element to atomize the liquid waste as it is injected into the combustion chamber (2).

Progressive cavity pumps usually are used to pump sludges which, in turn, are discharged directly into the combustion zone at a controlled rate by water-cooled lances (3).

Solids are generally considered to be the most difficult materials to burn because they are neither pumpable nor atomizable. If possible, some form of particle size reduction of bulk solids by means of crushing, grinding or shredding should be done. Solids may be fed into the combustion chamber by means of rams, gravity feed chute, air lock feeder, vibrating feeder, screw feeder or belt feeder. It is best that they be fed at as even a rate as possible to minimize transient conditions in the incineration train. Containerized solids can also be fed to some incinerator types, usually via an air lock, gravity feed, or a ram. If solids are charged on a batch or semi-batch basis, control of the incineration process is more difficult because combustion air requirements are usually greater shortly after the solids are fed than near the end of the batch feed period. The significant factor from a design and operating point is the rate of heat release of the material to be thermally destroyed.

LIQUID INJECTION INCINERATION

Liquid injection incineration is a well-developed technology with many units in operation. Liquid injection incinerators are almost exclusively applicable to pumpable and atomizable liquid wastes with little ash residue (4).

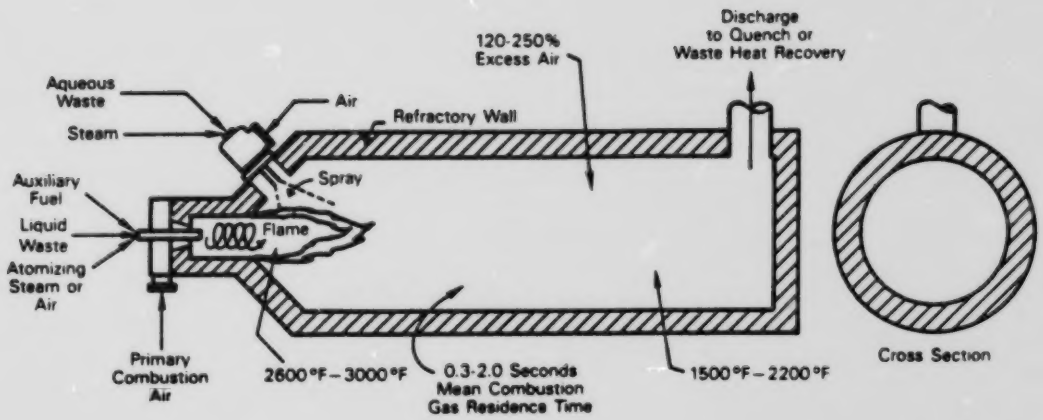


FIGURE 4-2

Typical Liquid Injection Combustion Chamber
(After Oppelt, 1987)

Generally, the viscosity of the liquid to be burned must be less than 10,000 SS (5). Figure 4-2 illustrates the basic elements of a liquid injection incinerator. The combustion chamber usually consists of a cylindrical-shaped refractory-lined vessel and a series of atomizing nozzles or waste burners. The axis of the cylinder may be oriented in either the horizontal or the vertical direction.

The burner orientation as well as the internal baffling can create either an axial, radial or tangential flow as desired to increase turbulence and improve combustion conditions in the incinerator. Swirl or vortex burner designs also help to achieve this goal (3). Typical combustion chamber residence times and temperatures range from about 0.5 to 2 seconds and from about 700 to 1,650°C respectively (6). Liquid injection incinerators often are used as an afterburner to ensure complete combustion following another type of primary combustion unit such as a rotary kiln.

A typical capacity of a liquid injection incinerator is about 10×10^6 kJ/h (10×10^6 BTU/h) and units as large as 70 to 100×10^6 kJ/h (70 to 100×10^6 BTU/h) have been built (7).

The main advantages of liquid injection incinerators are (7):

- No secondary combustion chamber is needed if the primary combuster has enough residence time - say 2 seconds as a general rule of thumb.
- They are capable of incinerating a wide range of liquid hazardous waste.
- No continuous ash removal system is required other than for downstream air pollution control systems.
- They are capable of a fairly high turndown ratio.
- There are virtually no moving parts.
- They have low maintenance cost.

The main disadvantages of liquid incinerators are (7):

- Only waste which can be atomized through a burner nozzle can be incinerated.

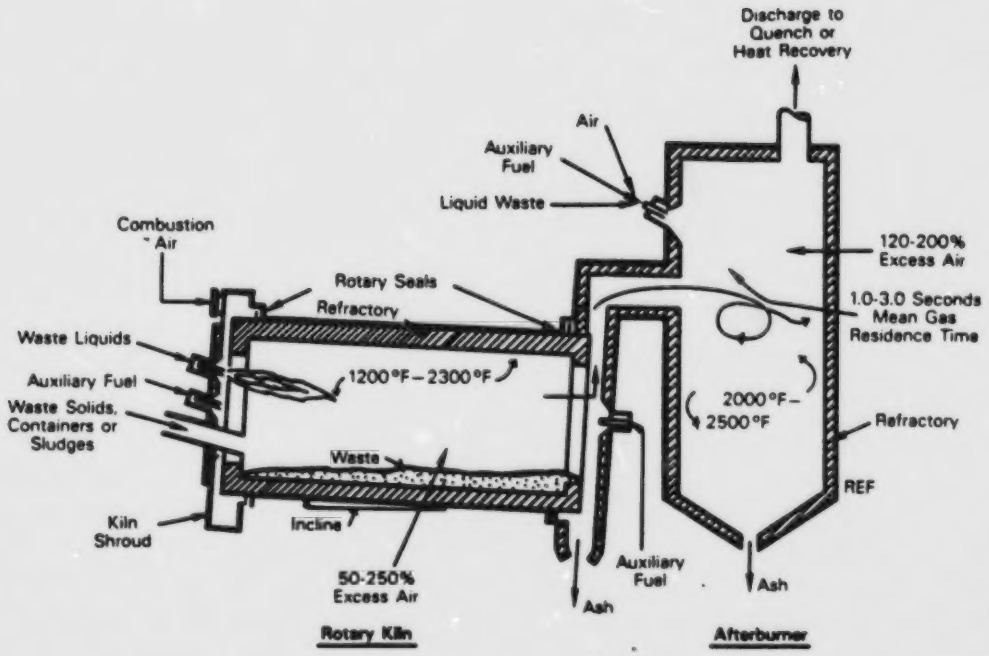


FIGURE 4-3

Typical Rotary Kiln/Afterburner Combustion Chamber
(After Oppelt, 1987)

- Burners are susceptible to pluggage if solids are suspended in the liquid waste feed stream.
- Burners may or may not be able to accept a material which dries and cakes as it passes through the nozzles.

ROTARY KILN INCINERATION

The rotary kiln incinerator has achieved considerable popularity because of its ability to handle the wide variety of feedstock types (including drums and other containers) commonly encountered in the hazardous waste management field (6). In fact, the rotary kiln essentially has become the universal technology of choice for central hazardous waste treatment facilities in Europe (8). Figure 4-3 shows a schematic illustration of a rotary kiln incincerator plus afterburner.

The rotary kiln itself consists of a cylindrical refractory-lined shell mounted on a slight incline. The rotation of the kiln promotes the agitation of solid wastes at the bottom of the kiln and the slight incline promotes the transport through the kiln of ash and solid residuals remaining as the wastes are combusted. Solid retention times in the kiln are typically 1 to 1.5 hours to ensure complete burnout of the organic matter. The solids retention time is controlled by the rotation rate of the kiln which is generally in the order of 1 to 5 rpm (3)(6).

The kiln is maintained at a typical operating temperature range of 650 to 1250°C (although it could be higher) by means of injecting either liquid wastes or auxiliary fuel or both through atomizing nozzles into the kiln environment.

Inside the kiln, solid wastes are converted to gases by means of a series of volatilization, destructive distillation, and partial combustion mechanisms. Some of the gaseous products of incomplete combustion are oxidized to ultimate end products in the kiln environment, but many pass out of the kiln and into an afterburner where they are oxidized in the presence of excess air and additional heat provided by liquid wastes or auxiliary fuel (3)(6).

Two schools of practice have developed for specifying the design and operating conditions of rotary kiln systems destroying hazardous wastes (8)(9). No clear preference has emerged as yet. One school maintains high operating kiln temperatures (say approximately 1300°C) to ensure that a molten slag is formed and that there is less residual hydrocarbon content in the quenched slag. The other school maintains that sufficient hydrocarbon burnout of the ash occurs at 900 to 1,000°C in the kiln and that any unburned hydrocarbons in the combustion gases will be oxidized in the >1,200°C several second residence time environment of the afterburner. Detractors of the slagging mode of operation claim that it causes a shorter refractory life while proponents claim that the molten slag coats and protects the refractory lining. Operation in the slagging mode is more popular in Europe where regulations require complete burnout of the ash. On the other hand, more regulatory emphasis is placed on the stack emissions in the United States.

Rotary kiln capacities typically are designed in the range of 25 to 60×10^6 kJ/h (25 to 60×10^6 BTU/h) and units as large as 90×10^6 kJ/h (90×10^6 BTU/h) have been built (3)(7). It is important to take special care in preparing the feedstock mix for a rotary kiln system. Many solid and/or highly chlorinated liquid organic wastes that are particularly suited to destruction by rotary kiln technology, have relatively low thermal valves and require the addition of either high thermal value wastes or supplemented fuel to be incinerated effectively. Thus the feedstock to the kiln system must be balanced carefully to ensure optimum performance consistent with least fuel cost.

A noteworthy variation of the rotary kiln design called the "rocking kiln" has been installed at the Alberta Special Waste Treatment Centre in Swan Hills, Alberta (10)(38). The kiln shell, instead of rotating through a 360° revolution, rocks slowly back and forth through approximately 45° to agitate the solid wastes and promote complete burnout. In this manner, a smaller and less expensive installation is possible that possesses much of the versatility of the rotary kiln in that it can process drummed wastes. While in a rotary kiln facility, the solid combustion residues are discharged continuously; in the rocking kiln ,they are discharged periodically by rotating the kiln 180° and allowing the residuals to fall by gravity into a quenching

vessel through the flue gas vent that normally connects to the afterburner chamber on the top of the kiln. Typical capacities of a rocking kiln can be as low as $3x10^6$ kJ/h ($3x10^6$ BTU/h). The Swan Hills facility currently is undergoing a series of commissioning tests for licensing and, once these are completed successfully, the rocking kiln can be considered to be proven technology.

The main advantages of rotary kiln incineration are (7):

- They can maintain a high residence time and incinerate a wide variety of liquid and solid hazardous wastes.
- The larger units have feed capabilities for drums and bulk containers.
- Ash removal is continuous and should not interfere with the waste oxidation.
- The retention time of the non-volatile waste components can be controlled by adjusting the rotational speed.
- Rotary kilns can be operated at temperatures as high as 1,400°C making them well suited for the destruction of toxic compounds that are difficult to degrade thermally.

The main disadvantages of rotary kiln incineration are (7):

- The rotary kiln system has a relatively high capital cost and maintenance cost.
- Spherical or cylindrical items may roll through the kiln before complete combustion.
- High particulate loadings in the combustion gases will require effective exhaust gas particulate removal systems.
- Problems in maintaining seals at either end of the kiln are a significant operating difficulty.
- Drying of aqueous sludge waste or melting of some solid wastes can result in clinker or ring formation on refractory walls.
- Particular care must be taken to avoid thermal cycling of the kiln system as this has a deterimental effect on the refractory lining. Such continuous operation of the kiln system requires large quantities of carefully prepared and thermally balanced feedstock; otherwise significant amounts of supplemental fuel will be required to maintain stable operating temperatures.

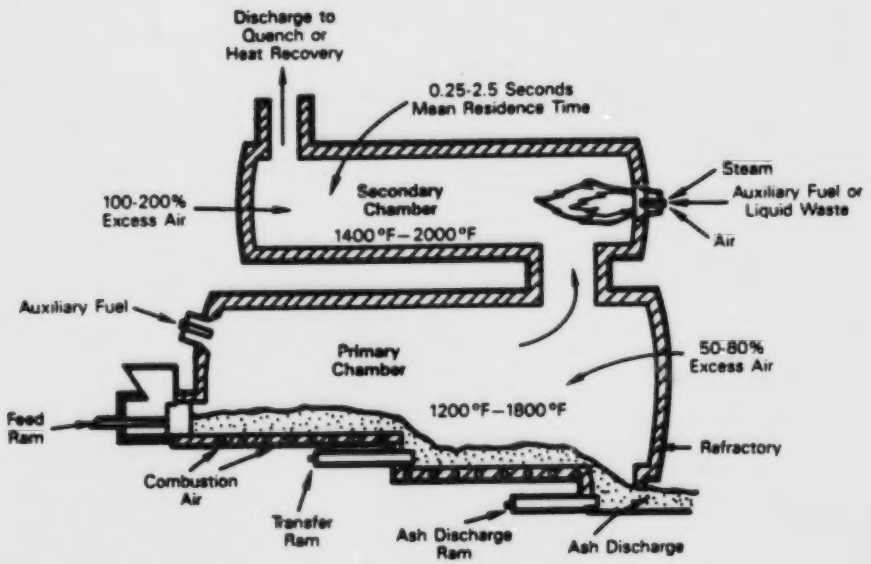


FIGURE 4-4

Typical Controlled Air Combustion System
(After Oppelt, 1987)

FIXED HEARTH INCINERATION

Fixed hearth incinerators, also known as controlled air, starved air or pyrolytic incinerators, also employ a two-stage combustion process as illustrated in Figure 4-4. Both combustion chambers usually are cylindrical in shape and refractory-lined. In the primary combustion chamber, solid waste is fed by means of a ram mechanism and burned on grates at 50 to 80 percent of stoichometric air requirements and at temperatures of about 650 to 950°C. This lack of excess air causes most of the volatile fraction of the waste to be destroyed pyrolytically, with the required endothermic heat provided by the oxidation of a portion of the fixed carbon. The resulting smoke and gaseous products of partial combustion pass to the secondary combustion chamber where additional air is injected to complete the combustion process at temperatures typically ranging from 150 to 1,000°C and residence times from 0.5 to 1.0 seconds. Depending upon the energy value of the waste, supplemental fuel may be required in either the primary or secondary combustion sections or both (2)(3)(7).

Because of physical limitations associated with the ram feeding mechanism which transports the waste/ash through the primary combustion chamber, controlled air incinerators generally tend to be physically smaller and have smaller processing capacities than either liquid injection or rotary kiln incinerators. This results in a lower capital cost; however, some degree of flexibility is lost because controlled air incinerators cannot handle the wide variety of feed types that the rotary kiln can.

Controlled air incinerators are considered established technology and often are used to incinerate hospital wastes, municipal solid wastes, as well as other hazardous liquid and solid wastes. They are constructed in modular skid-mounted units and can be shipped pre-assembled to the site for installation.

The main advantages of controlled air incinerators are (7):

- They are well suited to sludge disposal.

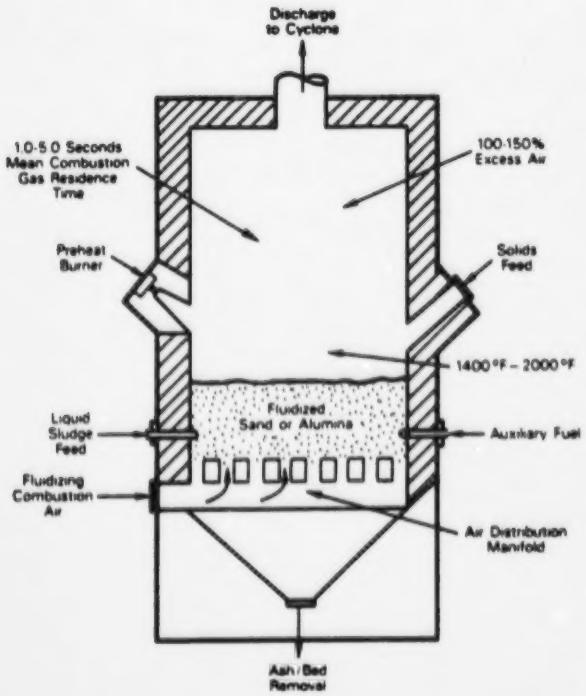


FIGURE 4-5

Typical Fluidized Bed Combustion Chamber
(After Oppelt, 1987)

- Large quantities of waste-bound water can be evaporated.
- They can utilize many types of fuel including coal dust, diesel fuel, waste oils and solvents.
- For multi-zone configuration hearths, fuel efficiency is high and it improves with the number of hearths used. Fuel burners can be added to any of the hearths to maintain a desired temperature profile.

The main disadvantages of controlled air incinerators are (7):

- Need for a secondary combustor, thus increasing installation, maintenance and operating costs.
- Depending on the size of the ram feeding mechanism, larger solid wastes may require pre-treatment for size reduction prior to incineration.
- Not well suited for wastes containing fusible ash, wastes which require extremely high temperature for destruction, or irregular bulky solids.

FLUIDIZED BED INCINERATION

Fluidized beds have been used in the chemical process industry for many years as reactor vessels. More recently over the last decade or so, they have gained acceptance for the thermal destruction of sewage sludges and municipal solid waste and now are being promoted as suitable for hazardous waste destruction applications (2)(3)(9). Fluidized beds are also used as catalytic incinerators for the thermal destruction of volatile organic carbon emissions (11).

A typical fluidized bed is illustrated in Figure 4-5. The combustion chamber consists of a single refractory-lined vessel, usually cylindrical in shape with the cylindrical axis oriented in the vertical direction. The vessel is partially filled with graded sand, alumina, sodium carbonate or other granular material and combustion air is supplied from a "windbox" beneath the bed at a rate sufficient to fluidize the bed. Auxiliary fuel, liquid wastes and/or sludges can be injected directly into the bed. Shredded solid wastes or sludges also can be fed from a feed port in the side of the vessel above the bed. The freeboard section between the fluidized bed

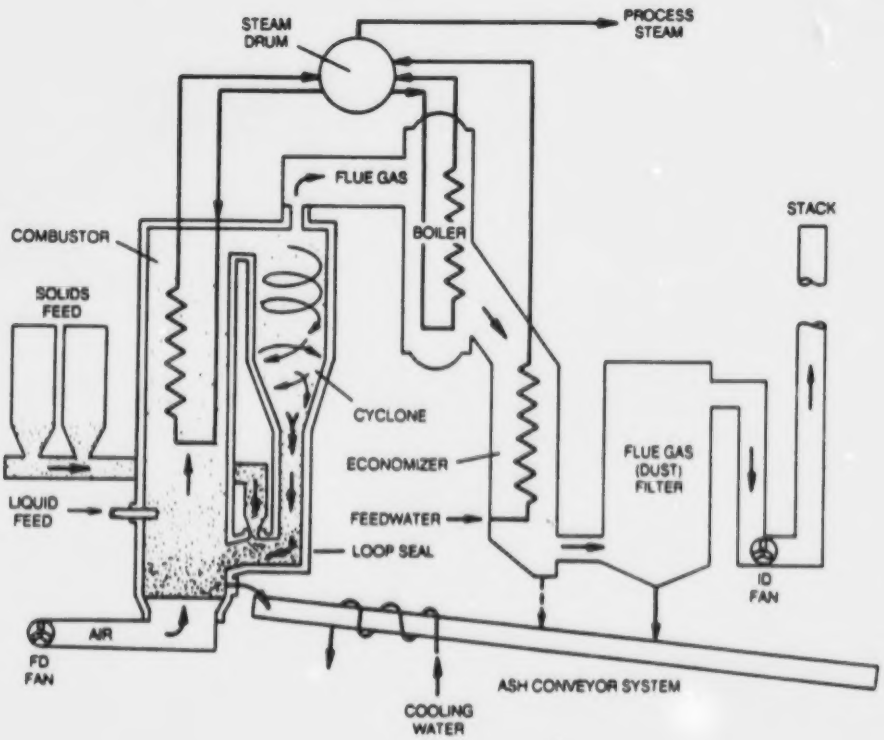


FIGURE 4-6

Sketch of Circulating Bed Combustor

(After The Hazardous Waste Consultant, May/June, 1988)

surface and the top of the reaction vessel allows for the separation of bed materials and ash from the gaseous products of combustion before they exit the vessel. The presence of sodium and/or potassium salts in the waste feed to a fluidized bed incinerator must be given careful consideration. They may form eutectic mixtures which can cause the bed to melt and defluidize (12).

Operating temperatures of fluidized bed incinerators range from 700 to 1,050°C with 800 to 850°C being typical. Gas residence times are usually several seconds and excess air requirements range from 100 to 150 percent (3)(13). Heat release rates overall can be high, ranging from 3,500 to 7,000 kJ/m^3 (100,000 to 200,000 BTU/ft^3).

A low-temperature two-stage fluidized bed combustion system has been designed to the pilot plant stage by Rockwell International Corporation for the U.S. Department of Energy to incinerate mixed hazardous and low-level radioactive wastes (38). The two fluidized bed vessels are of 316 stainless steel construction and, because of the relatively low operating temperatures, are not refractory-lined. The primary reactor contains a fluidized bed of sodium carbonate and chromic oxide on alumina particles. Acid gases formed during combustion in the primary bed react with the sodium carbonate to form sodium chloride, sodium sulphate and sodium phosphate. The chromic acid/alumina particles act as a catalyst to lower the temperature at which hydrocarbons are oxidized (say to 500 - 600°C). The secondary combustion chamber contains chromic oxide/alumina particles and acts as an afterburner.

A recent variation of the fluidized bed incinerator is the circulating bed combustor (2)(3)(6)(14)(15). In the circulating bed system, the fluidizing air is fed at a rate such that the bed granules are not merely fluidized, but rather are entrained in a highly turbulent environment and carried out of the vessel, separated in a cyclone, and returned to the bottom of the combustion chamber. The combustion chamber is of a "water wall" construction to remove the heat of combustion from the system without locating cooling tubes in the direct path of the solids. A circulating bed combustion system is sketched in Figure 4-6. The highly turbulent recirculating bed results in a high heat transfer efficiency and in a relatively uniform

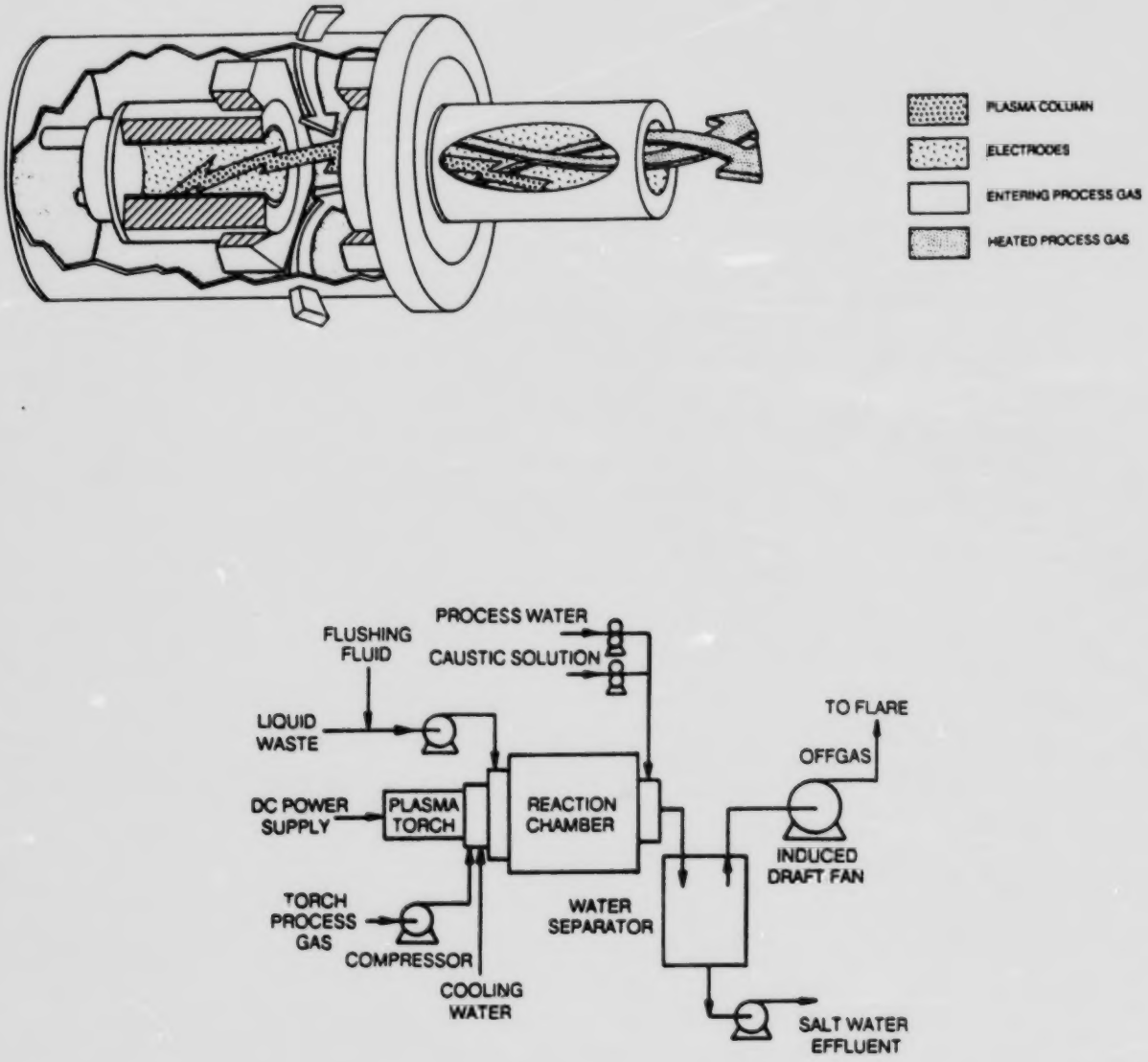


FIGURE 4-7

Sketch of Plasma Torch (top) and Pyroplasma™ Process Schematic (bottom) (After The Hazardous Waste Consultant, May/June, 1988)

temperature throughout the combustion zone and cyclone loop. Ash slagging problems often encountered in other types of incinerators burning solid wastes are avoided.

The main advantages of fluidized bed incinerators are (2)(3):

- High turbulence and correspondingly high heat transfer efficiencies in the combustion zone.
- Potential for in-situ acid gas neutralization by lime, limestone or sodium carbonate addition to the bed.
- Ability to process sludges and smaller solids (say less than 5 cm).
- Ability to process difficult-to-atomize wastes.

The main disadvantages of fluidized bed incinerators are (2)(3):

- Relatively high auxiliary fuel quantities required to bring combustion bed up to temperature.
- Need to shred large solids before adding them to the bed.
- Potential for agglomeration of bed if salts are present in the waste feed stream.

PLASMA ARC PYROLYSIS

Plasma arc technology for the pyrolytic destruction of hazardous wastes is an emerging technology that has been demonstrated on laboratory bench and full-scale (4 kg/min) prototype units. Plasma arc systems for hazardous waste destruction have been developed and marketed by Westinghouse Plasma Systems and Arc Technologies Company (38). A typical process schematic is pictured in Figure 4-7. The heart of the system is a reactor vessel in which a gas stream is activated to the plasma state by a continuous direct current electrical discharge to form a plasma arc. Liquid waste compounds are introduced into the discharge of the plasma arc and therein are chemically reduced (pyrolyzed) at temperatures of approximately 10,000°C. At these temperatures, chemical compounds dissociate into their atomic states. The exhaust gases from a reaction vessel are quickly passed to a

caustic scrubber wherein they are quenched to re-combine into relatively simpler and safer substances such as hydrogen, carbon, hydrogen chloride, carbon monoxide, acetylene, ethene, and other simple molecules. The scrubbed exhaust gas may be used as a fuel gas. Electrical energy required to produce the arc is in the order of 0.84 kWh/kg of waste fluid. It is claimed that the system produces about three times as much fuel energy per unit of waste than the energy required to destroy the waste (13)(16)(17)(18).

The current state of development of the plasma arc is the construction of two mobile prototype units of 6 and 18 tons per day nominal capacities (38). Testing of these units using methyl ethyl ketone/methanol, carbon tetrachloride and PCB feed materials show considerable promise and the destruction and removal efficiencies of principal organic hazardous constituents are well in excess of 99 percent. In fact, the destruction and removal efficiency for a liquid feed containing 43 percent carbon tetrachloride was measured at greater than 99.99 percent and for 14 percent PCB's, greater than 99.9999 percent (16). A contract has been awarded for full-scale demonstration of the unit to destroy sludge generated during the course of leachate treatment at the Love Canal site near Niagara Falls, New York. The major task for further development is to increase the long-term endurance of the unit (13).

Westinghouse Plasma Systems' Pyroplasma process is perhaps the furthest along in the development and application stages. It is based on technology originally developed at the Royal Military College in Kingston, Ontario.

WET OXIDATION

Wet oxidation has been an established process for treating sewage sludges for several years. Recently, considerable development work has been done by proponents of the process (Zimpro, VerTech, Oxidyne, Kenox) to adopt the process for destruction of organic hazardous wastes. Thus it is considered to be an emerging technology for hazardous waste treatment.

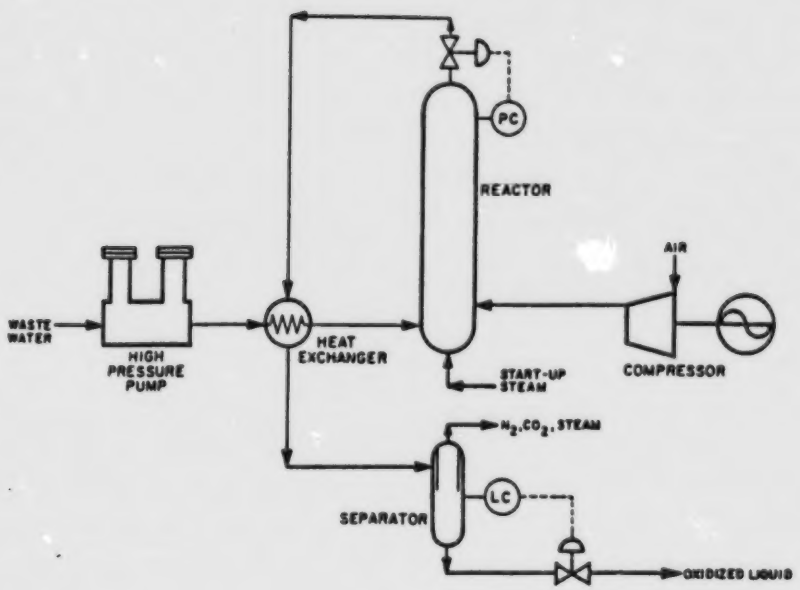


FIGURE 4-8

General Schematic - Zimpro Wet Oxidation System
(After Turner, 1986)

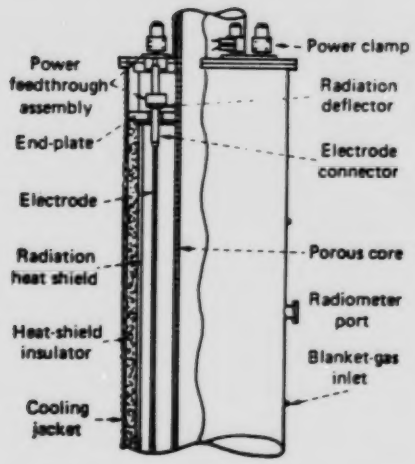
A schematic of the Zimpro wet oxidation process is illustrated in Figure 4-8. The essential feature of the process is the aqueous phase oxidation of organic and inorganic materials at high pressure (typically 10,000 kPa or 1,500 psi) and moderately high temperature (200 to 300°C) in a pressure vessel with approximately one hour retention time. Waste is preheated by treated effluent and pumped into the reactor along with compressed air or pure oxygen. Four types of vessels are used:

- A stirred tank reactor
- A bubble column contactor
- A 1.5 km deep underground shaft with concentric downcomers and upcomers for waste and heat transfer fluid.
- A long coiled plug flow tubular reactor.

Both VerTech Treatment Systems, Inc. and Oxidyne Inc. have developed to the full-scale demonstration stage vertical tube reactor technology that employs concentric downcomers and upcomers placed in a deepwell. The VerTech system operates in subcritical conditions in a well drilled approximately 1 to 1.5 km deep. A heat transfer fluid is employed to provide heat to initiate the oxidation reaction and then to withdraw heat once the reaction is under way.

The Oxidyne system uses a deeper well (approximately 3.5 km depth) to achieve supercritical conditions near the bottom into which a stream of oxygen is fed to cause rapid oxidation of the organics in the waste. VerTech have demonstrated their process successfully on the full-scale treatment of sewage sludge at Longment, Colorado; Oxidyne presently are constructing a full-scale sewage sludge treatment facility at Houston, Texas. Both firms, as well as Kenox Corporation of Toronto, are developing pilot and full-scale on-surface (i.e. not deepwell) systems for hazardous waste treatment (38).

Generally, wet air oxidation is applicable to wastes that are too dilute for incineration but too concentrated and/or toxic for biological treatment. Total organic carbon removals of 80 to 90 percent or better are reported and recent reports on specific hazardous organic compound destruction by wet



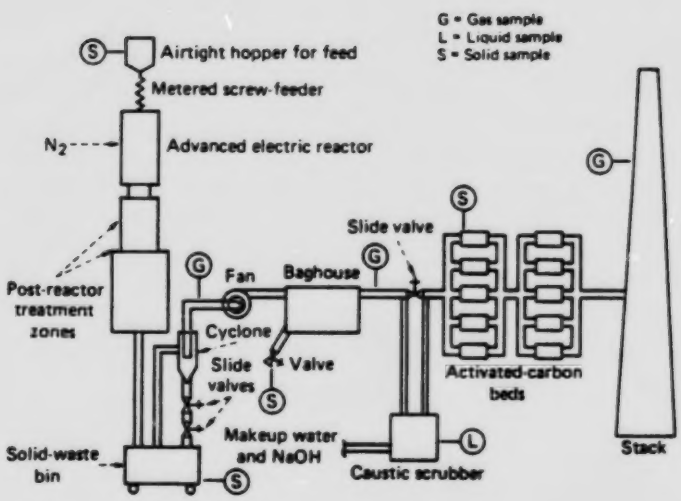


FIGURE 4-9

Sketch of Advanced Electric Reactor Vessel & Thermal Destruction System (After Lee et al, 1984)

oxidation has shown considerably better destruction and removal efficiencies than this (19). In batch laboratory tests, greater than 99 percent destruction of aliphatic, halogenated aliphatic and aromatics was obtained; however, halogenated aromatic compounds were resistant to destruction under conventional wet oxidation operating conditions (4). The products of combustion dissolved and suspended in the aqueous carrying liquid generally will require further treatment before discharge to the environment. This can be done either by aerobic or anaerobic biological treatment systems, or by activated carbon adsorption or by both.

INFRARED PYROLYSIS

Infrared radiation is employed in two recently-developed processes for the destruction of hazardous wastes. The processes are particularly suited to solid wastes contaminated with halogenated hydrocarbons, dioxins and furans. The infrared process is considered to be an emerging technology and a few full-scale units have been constructed. The results appear to be promising.

One process which is marketed by J.M. Huber Corporation is called the Advanced Electric Reactor and is sketched in Figure 4-9. The primary reactor employs intense thermal radiation created by high impedence carbon electrodes surrounding a vertical porous cylindrical graphite core. The reactants (wastes) are isolated from the reactor core walls by means of a gaseous blanket formed by passing nitrogen gas radially inward through the porous graphite core walls. The heat from the carbon electrodes causes the reactor core walls to heat to incandescence, thereby transferring near-infrared thermal energy to the wastes and causing the wastes to pyrolyze at approximately 2,200°C. The wastes and off-gases pass through two post-reactor treatment zones. The reaction vessel for the first zone is insulated and provides an additional 5 seconds of retention time for the off-gases at a temperature of about 1,400°C. The reaction vessel for the second zone has a water-cooled jacket and provides an additional 10 seconds of retention time at about 550°C. Residual solids are collected in a sealed bin; the off-gases are routed through a cyclone to collect large particulates, and further exhaust gas cleaning is provided by a baghouse/scrubber/

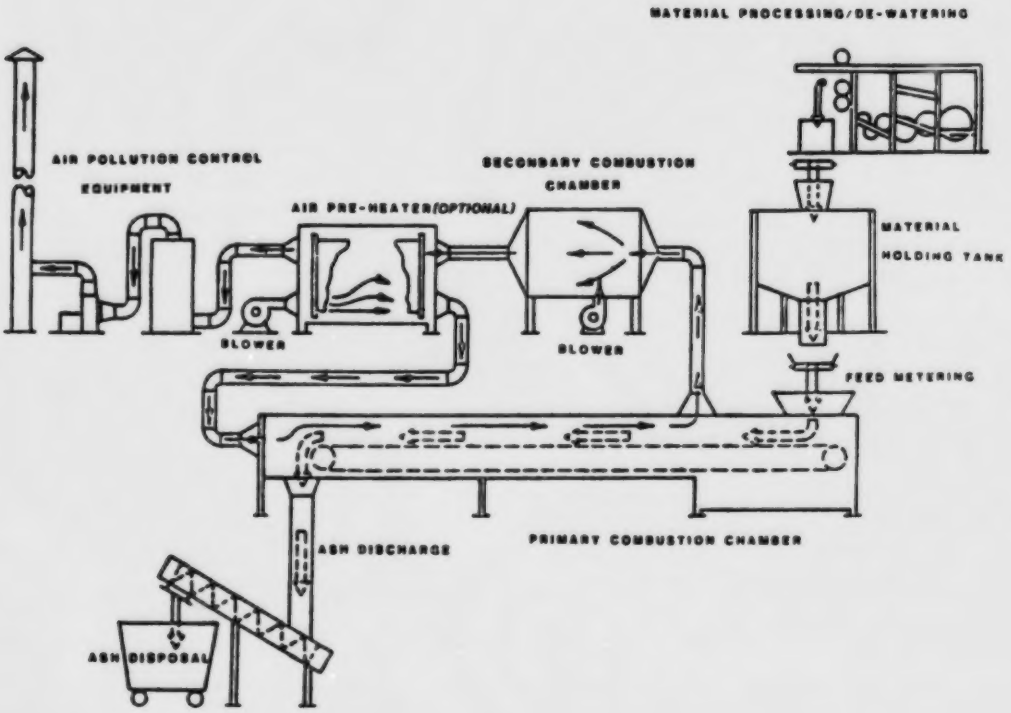


FIGURE 4-10

Sketch of Shirco Infrared Incineration System
(After Versar, Incorporated, 1986)

activated carbon bed train. Destruction and removal efficiencies of 99.9999 percent or better have been measured on a carbon tetrachloride and PCB waste stream. In addition, soils containing dioxin have been treated to the extent that no measurable dioxin remained in either the residual solids or in the exhaust gases (6)(20)(21).

The other infrared process under development is the Shirco infrared system in which the primary combustion chamber consists of a moving conveyor belt which transports the solid waste to be burned through an enclosed insulated rectangular box-shaped reactor. Infrared energy is provided by electrical heating elements along the length of the furnace. The heating elements create temperatures in the wastes in the range of 250 to 1,000°C (typically 850°C). Solid residence times in the primary combustion chamber vary from 10 to 180 minutes depending on the speed of the conveyor. A secondary combustion chamber equipped with a propane auxiliary burner is used to incinerate the primary off-gases at 300 to 1,250°C and residence times of about 2 seconds (22). A sketch of the Shirco system is illustrated in Figure 4-10. Tests conducted on dioxin-contaminated soils showed destruction and removal efficiencies greater than 99.9999 percent in the exhaust gases with no detectable dioxin in the residual solid phase. The developer of the process claims that it offers a number of potential economic advantages including: no need for an expensive robust refractory lining in the primary chamber because solids do not impinge on the walls; solids (such as contaminated soil) are not volatilized, thereby reducing energy requirements; and, the solids are only minimally agitated during primary combustion, thereby reducing particulate carry-over (12). Potential problems of conveyor belt corrosion have been reported with contaminated soils containing certain salts, sulphur and chlorinated compounds.

MOLTEN SALT INCINERATION

Molten salt incinceration is an emerging technology that has been developed to full-scale demonstration stage by Rockwell International. For hazardous waste applications, a 100 kg/h unit has been constructed for PCB destruction. Units as large as 900 kg/h have been constructed for coal gasification studies (38).

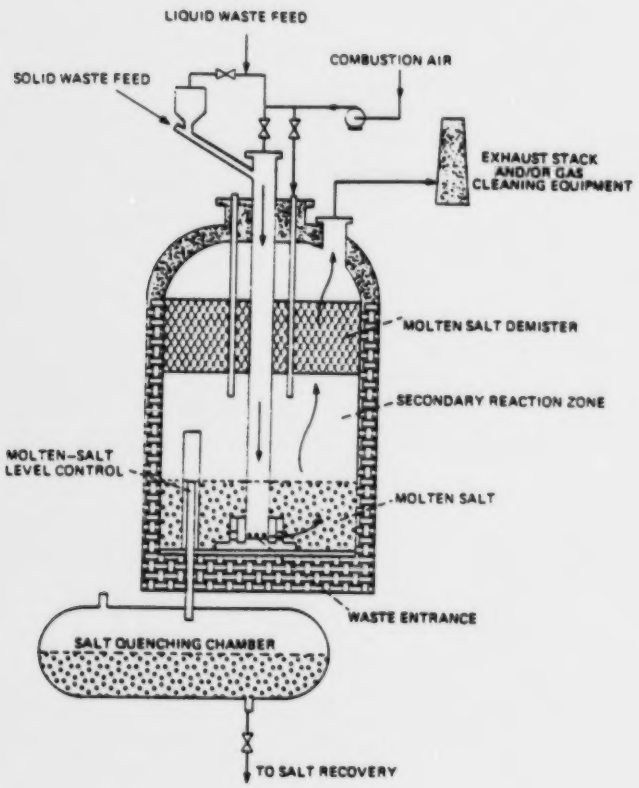


FIGURE 4-11

Sketch of Molten Salt Incineration Vessel
(After Reid Crowther, 1981)

In the molten salt process, a refractory-lined reaction vessel contains a pool of molten sodium carbonate which acts as an heat transfer medium, an acid gas absorber, and an oxidation catalyst. The waste materials along with combustion air (or oxygen) are fed into the bottom of the vessel so that any gases formed during the combustion process are forced to pass upward through the molten salt pool. In this manner, acidic products of combustion such as hydrogen chloride produced by the oxidation of chlorinated organics are neutralized by the alkalinity of the molten solid bed. The molten bed is replaced periodically as the neutralized acid gas products accumulate to approximately 20 percent impurity by weight.

A sketch of a molten salt incinerator is illustrated in Figure 4-11. It is claimed that the process is particularly suited to the destruction of halogenated wastes because of its inherent ability to scrub the off-gases. However for highly chlorinated wastes, the cost of bed replacement may be high, as 1 kg of bed material may be required for every kilogram of waste destroyed (13). In addition, it is not suitable for high ash content wastes (5).

Rockwell International, the developer of the process, are seeking licences for the technology (38).

SUPERCRITICAL FLUID INCINERATION

The critical point of water is 374°C and 22,100 kPa. Above this region, water becomes an excellent solvent for both oxygen and organic wastes whereas inorganics are essentially insoluble in supercritical water. These properties have led to a development of an incineration system that operates in the supercritical region and provides rapid oxidation of organics with a resulting off-gas stream that is virtually free of inorganics.

A supercritical incineration system using water as a supercritical fluid has been developed by MODAR Company and is sketched in Figure 4-12. The following steps occur in this process (6)(38):

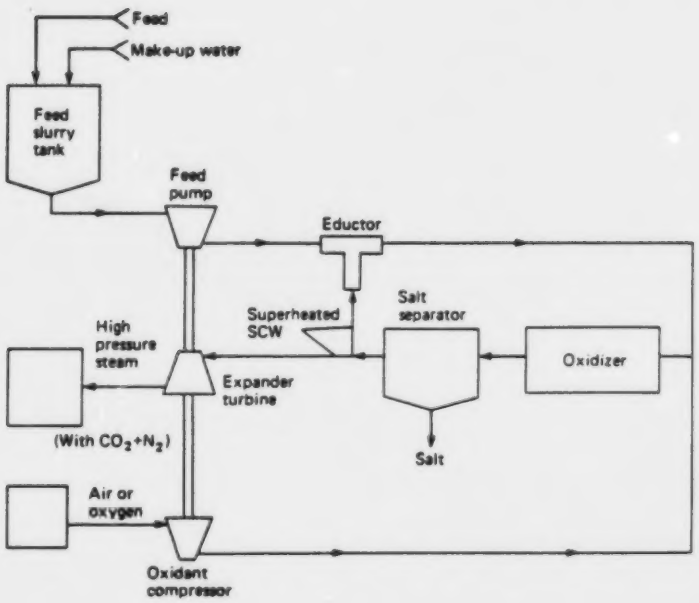


FIGURE 4-12

Sketch of Supercritical Fluid Incineration System (After Freeman & Olexsey, 1986)

- Waste is slurried with make-up water to provide a mixture of 5 percent organics. The mixture is heated using previously processed supercritical water and then pressurized.
- Air or oxygen is pressurized and mixed with the feed. Organics are oxidized in a rapid reaction.
- The reaction time is less than one minute.
- Chlorine, sulphur and phsophorus in the waste are converted to the corresponding chlorides, sulphates and phosphates. Caustic can be added to the feed to neutralize excess acid-forming inorganics.
- The effluent from the oxidizer is fed to a salt separator where inorganics are precipitated.
- Waste heat from the process can be reclaimed to provide sufficient energy for power and high pressure steam.

Bench-scale experiments have indicated that the process is capable of organic carbon destruction efficiencies in excess of 99.9 percent; in fact, for a PCB/MEK mixture, the destruction and removal efficiency was in excess of 99.99 percent (6). The technology is particularly suited to the destruction of dilute aqueous wastes in the 1 to 20 percent organic content range (38).

The process is considered to be an emerging technology.

JOULE-MELTING FURNACE

Penberthy Electromelt Int'l Inc. has adapted electric molten glass furnace technology to the thermal destruction of hazardous wastes (23). A longitudinal cross-section of the furnace is sketched in Figure 4-13. The furnace consists of a rectangular refractory-lined tunnel which holds a pool of molten glass. The molten glass is kept hot (1300°C to 1400°C) by means of an electric current passing between submerged metal electrodes. The furnace gets its name from the "Joule effect", which is the heating of a conductor by means of passing an electrical current through it.

Waste materials, in the form of bulk liquids, sludges and solids, as well as in bags or other containers, are charged to one end of the furnace along

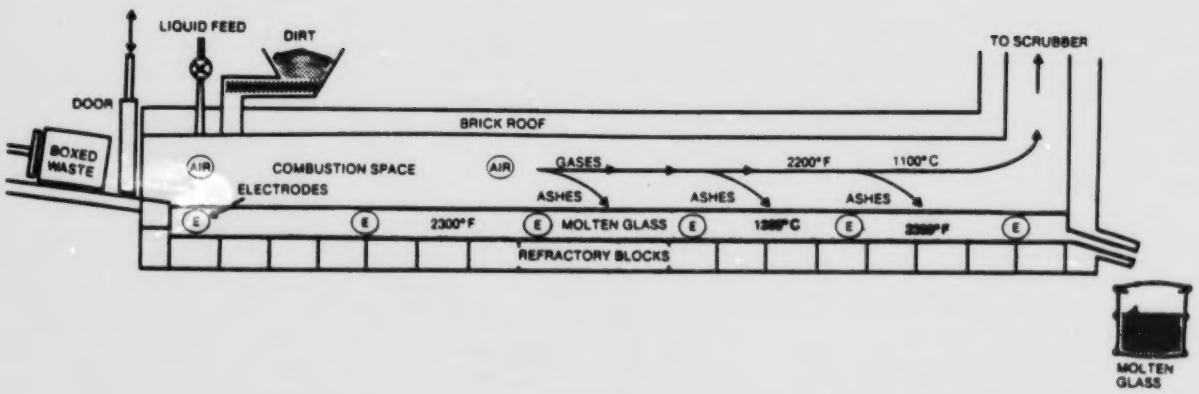


FIGURE 4-13

Sketch of Joule-Melting Furnace
(After Penberthy-Electromelt Int'l. Inc., 1984-88)

with a controlled supply of combustion air. Once in the hot furnace environment, a pyrolytic reaction occurs; solid residues drop into and dissolve in the molten glass phase; gases and vapours travel down the length of the furnace while the combustion reactions proceed toward completion. An exhaust gas scrubbing system is used to capture halogens and any fine particulate matter in the off-gases. As solids from the processed waste accumulate in the molten glass pool, excess glass is tapped from the furnace and quenched prior to disposal.

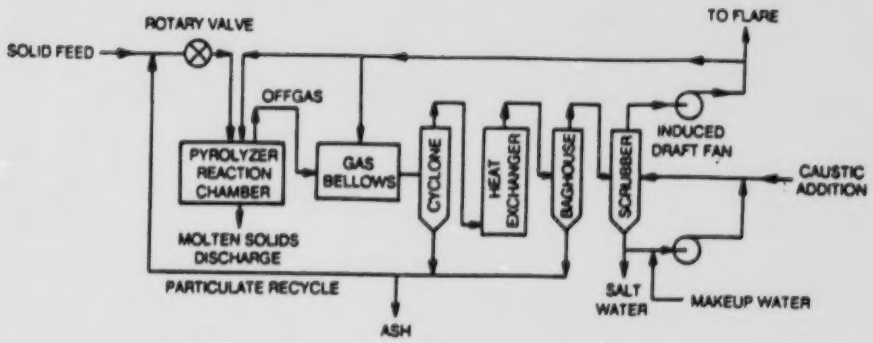
The developers of the process claim that it is suited to processing a wide variety of wastes including:

- Asbestos
- Arc Furnace Dust
- Incinerator Ashes
- Contaminated Soil
- Chloro-Organics
- Paint Solvents and Sludges
- Electroplating Sludges
- Military Wastes
- Bio-Medical Wastes
- PCBs
- Pot Liner from Aluminum Smelting
- Sludges from:
  - Water Purification
  - Municipal Sewage
- In-Plant Wastes (various kinds)
- Superfund Remedial, Including Soil and Lagoon Mud
- Pesticides

It is claimed that the solidified glass product is non-leachable and thus does not possess toxic properties. In a trial burn using a feed mixture of one-third trichlorethylene, the destruction efficiency for total chlorinated hydrocarbons was measured to be 99.9978 percent.

The main advantages of the Joule-Melting furnace are claimed to be the inertness of the residual solid glass product and the fact that relatively small furnaces (50 kg/h) can be built for use on site by a single hazardous waste generator to process his wastes into a non-hazardous final product that does not require special secure landfill disposal procedures.

The Joule-Melting furnace is considered to be proven and applied technology in the glass manufacturing field where furnace capacities range from 10 tons to 160 tons per day. For application to hazardous waste treatment, a 4 ton



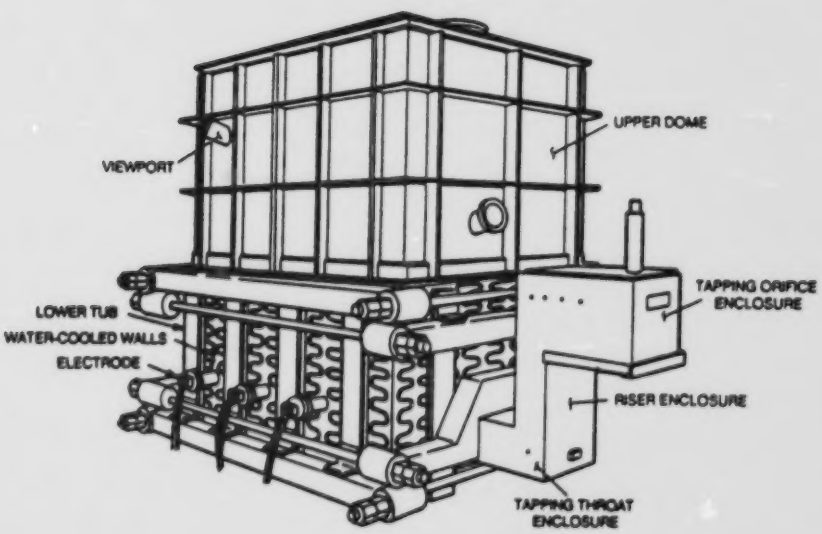


FIGURE 4-14

Sketch of Electric Pyrolyzer Process (top) and Electric Pyrolyzer Reactor (bottom) (After The Hazardous Waste Consultant, May/June, 1988)

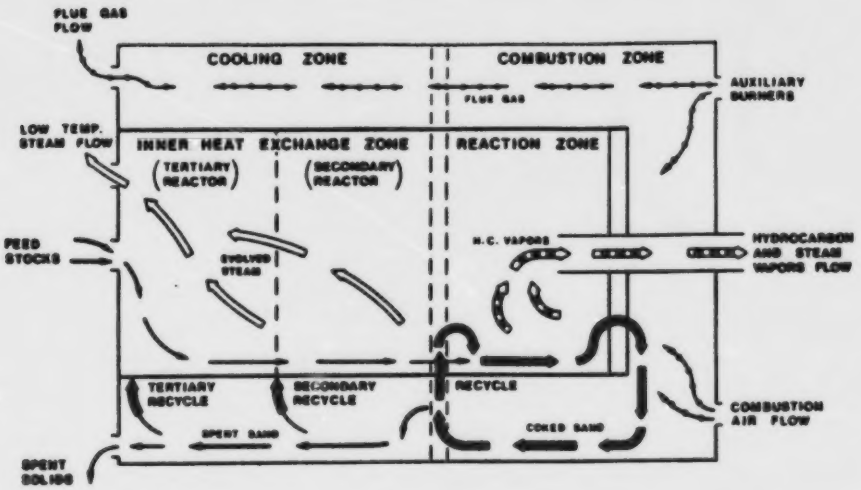
per day prototype unit has been constructed and has been operated successfully by the developer in Seattle, Washington. The developer is capable of supplying units for hazardous waste application in sizes ranging from 50 kg/h to 55 tonnes per day. Furnaces at the lower end of this size range are mobile (9 tpd) and transportable (22.5 tpd).

ELECTRIC PYROLYZER

A transportable electric pyrolyzer has been developed by Westinghouse's Environmental Technology Division and is sketched in Figure 4-14 (38). The electric pyrolyzer furnace is constructed in two sections: an upper dome and a lower tub. Both are refractory-lined and operate at about 1650°C using electrical energy. The organic content of waste solids, sludges, liquids and gases are pyrolyzed to carbon, carbon monoxide, hydrogen and acid gases in the absence of oxygen while the inorganic content is melted to form a glass-like residue. The off-gases are passed through a gas cleaning train and flared.

The lower tub portion of the reactor contains electrodes that pass electrical current through the molten material thereby creating heat from electrical resistance. The upper dome portion contains electric resistance heaters. The lower tub portion is forced-water cooled while the upper dome portion is forced-air cooled. Excess molten solids are drained periodically through a tapping system that connects at the bottom of the reactor.

Westinghouse has constructed a 5 ton per day prototype unit which is contained in two 42-ft trailers and is currently undergoing testing. A larger 100 ton per day unit is in the design stage (38).



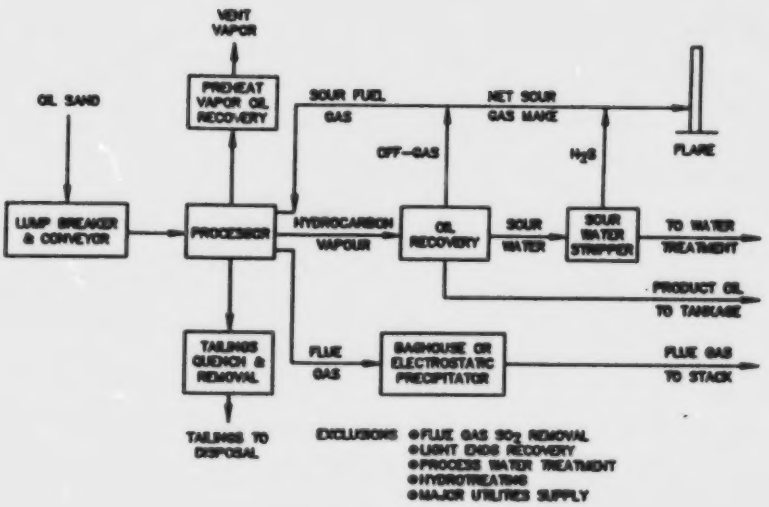


FIGURE 4-15

Schematic Diagram of Taciuk Processor (top) and External System Requirements (bottom) (After UMATAC Industrial Processes, 1988)

TACIUK PROCESSOR

The Taciuk Processor consists of a single horizontal rotary vessel which contains individual compartments in which the processing steps separate and recover various constituents of input feed materials (39). The Processor was developed originally for the processing of Alberta's oilsands and more recently has been adapted to the treatment of hydrocarbon-containing wastes, and the separation of hazardous wastes from contaminated soils.

Figure 4-15 presents a schematic diagram of the Taciuk Processor unit and the required ancillary processing equipment. The processing unit consists of two horizontal rotating concentric vessels - the inner vessel operating in a pyrolytic mode while the outer one operates in an oxidative mode. The inner vessel has two zones - the inner heat exchange zone wherein the feedstock is pre-heated and dried by means of heat exchange with the outgoing treated solids, and the reaction zone wherein the pre-treated materials are mixed with a recycle stream of hot sand. The elevated temperatures in the reaction zone cause the hydrocarbons in the feedstock to vapourize and thermally crack leaving a coke residue coating on the sand particles. The vapour stream exits the Processor directly from the inner vessel and is led to an oil recovery unit and/or further treatment. The coke-coated sand particles pass into the outer vessel and return toward the feed end of the processing unit in the annulus between the inner and otuer vessels. Combustion air is added to this annulus in order to burn the coke and to provide process heat. A portion of the hot sand is recycled to the reaction zone to provide heat for the pyrolytic reaction and the remainder enters an outer heat exchange compartment or cooling zone that provides heat to preheat the feedstock. The combustion gases are directed to a flue gas cleaning train.

Considerable bench scale and pilot plant development have been done on the application of the Taciuk Processor to the production of synthetic crude oil from tarsands and oil shales. A 4.5 tonne per hour pilot plant has been constructed and used to process not only tarsands, but also to treat heavy oil production wastes, refinery wastes, oil-contaminated materials from waste dumps, and wastes from remedial cleanup operations including PCB-

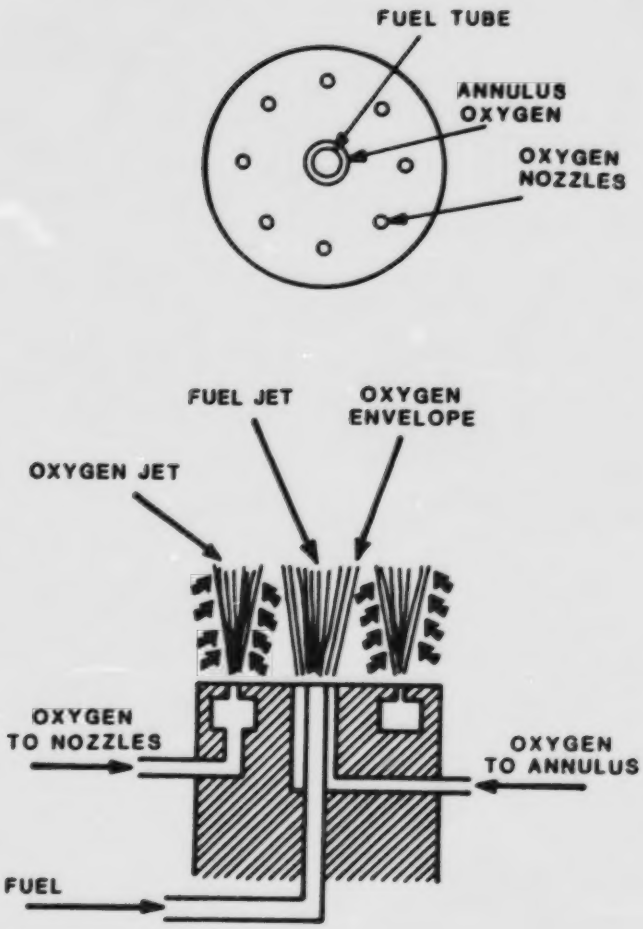


FIGURE 4-16

Schematic Diagram of the Linde Oxygen Combustion Burner

(After The Hazardous Waste Consultant, May/June, 1988)

contaminated materials. Larger capacity stationary and transportable units have not progressed beyond the design stage. The process is worth watching as a possible emerging technology for the treatment of hydrocarbon-contaminated soils.

OXYGEN-ENHANCED COMBUSTION

Linde Division of Union Carbide has developed an improved combustion burner technology that has the potential to increase the nominal rated capacity of many existing incineration systems (38). The system is sketched in Figure 4-16. The significant feature of the burner is that furnace gases are aspirated into the oxygen jets prior to mixing with the fuel. (This aspiration effect is illustrated by the small solid arrows in Figure 4-16.) In this manner, the flame temperature can be reduced to a value equivalent to air flame temperature thereby avoiding the problems often encountered with extremely high localized temperatures due to oxygen-enrichment in conventional burners.

There are several advantages claimed for this system:

- Air (79 percent nitrogen + 21 percent oxygen) is replaced by oxygen or oxygen-enriched air thereby eliminating the energy required to heat the nitrogen and move it through the flue gas system.
- No_x emissions are reduced.
- Flue gas volumes are reduced substantially thereby minimizing entrainment of fine particulates and reducing the load on the emission control system.
- The nominal capacity of existing incineration systems can be increased substantially because throughput is normally limited by flue gas volume, velocity and residence time.

The Linde system has been retrofitted to the U.S. EPA's Mobile Incineration System which is a small rotary kiln system. Throughput capacity was doubled from 0.9 tonnes per hour to 1.8 tonnes per hour and the amount of supple-

mental fuel was reduced significantly. The destruction and removal efficiency for PCB-containing wastes was in excess of 99.99999 percent. The technology is available for lease from Union Carbide.

In another adaptation of oxygen-enhanced technology applied to the incineration of hazardous wastes, American Combustion Inc. has developed the Pyretron Thermal Destruction System which consists of special auxiliary burners for the primary and secondary combustion chambers of existing incinerators; valve trains for supplying these burners with either auxiliary fuel or liquid waste, oxygen, and air; and a computerized control system (38). The control system senses impounding process upsets caused by irregularities in the feed compaction and makes appropriate adjustments to the oxygen level to maintain system pressure, temperature and oxygen conditions.

The Pyretron system has been retrofitted to a rotary kiln system and was found to successfully anticipate and correct for transient overloads caused when batch changes of waste were introduced to the kiln. In addition because oxygen is used, the nominal throughput capacity of the incinerator was doubled. Testing is continuing to assess the destruction and removal efficiency of the system.

CO-DISPOSAL IN INDUSTRIAL PROCESSES

A number of industrial processes use wastes either as a primary fuel or as a supplemental fuel. The larger installations typically include medium to large-sized industrial boilers, cement and aggregate kilns, and iron-making furnaces (24).

One application that is particularly attractive for the disposal of halogenated organics is the co-firing of a cement kiln with hazardous wastes. The cement clinker formed in the kiln is highly alkaline and acts as a scrubber to remove the acid gases generated in the combustion process. The operating temperatures in a cement kiln are typically 1,500°C with retention times in the order of several seconds. Care must be taken to ensure that the chlorine content in the feed does not exceed the ability of the cement pro-

	Plant	Date	Process	APCD	Fuel	Wastes
1	St. Lawrence Cement Mississauga, ON	1974 1975-76	Dry Wet	ESP ESP	Fuel Oil Fuel Oil	Waste oil Chlorinated organics
2	Stora Vika Sweden	1978	Wet	ESP	Coal	Chlorinated organics PCBs Freon 113
3	Marquette Cement Ogdensburg, IL	1981	Dry	ESP	Coal	Hydrocarbon solvents < 5% chlorine
4	San Juan Cement Puerto Rico	1981-82	Dry	Baghouse	Fuel Oil	Chlorinated organics
5	Alpha Cement Cementon, NY	1982	Wet	ESP	Coal	Solvents
6	General Portland Lebec, CA	1982	Dry	Baghouse	Coal	Hydrocarbon solvents
7	General Portland Paulding, OH	1983	Wet	ESP	Coal	Hydrocarbon solvents, Freon 113
8	Lone Star Industries Ogdensburg, IL	1983	Dry	ESP	Coal Coke	Hydrocarbon solvents, Freon 113
9	Rockwell Lime Manitowoc, WI	1983	Lime	Baghouse	Coke	Hydrocarbon solvents

Plant	Test Condition	Particulate Emission gr/scf[1]	lb/hr	lb/ton[3]	Chloride input to Kiln kg/Mg
St. Lawrence	Chlorinated aliphatics[1]	0.21	123	3	4.0
	Chlorinated aromatics	0.288	45	1.1	5.5
	PCBs	0.078	44	1.1	2.5
	Baseline	0.038	21	0.5	
	Lubricating oil	0.064	83	0.7	
	Baseline	0.107	139	1.1	
Rockwell Lime	Waste	0.018	2.2	0.26	2.7
	Baseline	0.013	2.0	0.24	
Stora Vika	Aliphatics	0.039	31	0.88	4.4
	Baseline	0.009	4.7	0.21	0
	PCBs	0.024	12.7	0.52	3.8
	Baseline	0.011	5.9	0.25	0
	Chlorophenols & Phenoxyacids	0.058	30.9	1.38	0.95
	Baseline	0.014	7.7	0.34	0
	Freon 113	0.062	33.3	1.39	1.7
	Baseline	0.022	11.7	0.49	0
Marquette	Waste solvents	0.014	58	21	1.1
	Baseline	0.093	80	20.8	
Alpha Cement	Solvents	0.041	44	0.8	
	Baseline	0.050	53	1.1	
San Juan	Wastes	0.043	22.4	0.88	5.5
	Baseline	0.041	21.7	0.84	
General Portland Paulding	Wastes	0.030	18.9	0.65	2.2
	Baseline	0.030	19.8	0.84	0.2
Lone Star	Waste[2]	0.17	116	2.0	1.2
	Baseline				0.2

[1] Process upset during test
[2] ESP malfunctioned during test
[3] kg of particulate emitted per ton of product material (cement)

Plant	Waste Component	Destruction Efficiency
St. Lawrence Cement	Chlorinated aliphatics	> 99.990
	Chlorinated aromatics	> 99.989
	PCBs	> 99.986
Stora Vika	Methylene chloride	> 99.995
	Trichloroethylene	> 99.9998
	All chlorinated hydrocarbons	> 99.988
	PCB	> 99.99998
	Chlorinated phenols	> 99.99999
	Phenoxy acids	> 99.99998
	Freon 113	> 99.99988
San Juan Cement	Methylene chloride	93.292-99.997
	Trichloromethane	92.171-99.98
	Carbon tetrachloride	91.043-99.998
Los Robles (General Portland)	Methylene chloride	> 99.99
	1,1,1-Trichloroethane	99.99
	1,3,5-Trimethylbenzene	> 99.95
	Xylene	> 99.99
Paulding (General Portland)	Methylene chloride	99.956-99.999
	Freon 113	> 99.999
	Methyl ethyl ketone	99.978-99.997
	1,1,1-Trichloroethane	99.991-99.999
	Toluene	99.940-99.988
Ogdensby (Lone Star)	Methylene chloride	99.94-99.99
	Freon 113	99.999
	Methyl ethyl ketone	99.997-99.999
	1,1,1-Trichloroethane	> 99.999
	Toluene	99.986-99.998
Rockwell Lime	Methylene chloride	99.9947-99.9995
	Methyl ethyl ketone	99.9992-99.9997
	1,1,1-Trichloroethane	99.9955-99.9982
	Trichloroethylene	99.997-99.9999
	Tetrachloroethylene	99.997-99.9999
	Toluene	99.995-99.998

TABLE 4-2

Summary of Cement & Lime Kiln Tests
(After Mournigham & Branscome, 1988)

duction process either to incorporate chlorine in the clinker or to reject it in the exhaust gas dust removal system. In this regard, the chlorine content generally should be 3 percent or less of the total fuel feed. As considerable amounts of fuel are used in the manufacture of cement, this still represents a substantial quantity of chlorinated organics. It is reported (24) that, when chlorine input exceeds about 6 kg Cl/Mg clinker, greater particulate emissions have occurred in kilns equipped with electrostatic precipitators for dust control; however, control of particulates from kilns equipped with baghouses was not a significant problem. Halogenated hydrocarbon removal, including PCBs, in cement kilns is reported to be in excess of 99.9999 percent (3).

There are several cement plants currently in operation in the United States using waste materials as supplemental fuel (25). The process is considered to be well beyond the demonstration and development stage (13). The results contained in a report on emission tests conducted at several industrial facilities are summarized in Table 4-2. In general, the results show that cement kilns, when well operated, can achieve destruction and removal efficiencies equal to those achieved by well designed and well operated hazardous waste incinerators (24).

One of the main advantages associated with this technology is that much of the necessary physical equipment has already been financed and constructed for other purposes. The major expense for adapting the existing process to handle hazardous wastes is related to the construction of the necessary feed storage, preparation and injection facilities. In addition, some modifications to the exhaust gas cleaning train may be required.

AIR POLLUTION CONTROL DEVICES

The off-gases from a hazardous waste incineration process contain not only carbon dioxide and water vapour as primary products of combustion, but also a multitude of other compounds in smaller concentrations including hydrogen chloride, chlorine, hydrogen bromide, hydrogen fluoride, oxides of sulphur, phosphoric pentoxide, oxides of nitrogen and particulate matter (3).

The most common system employed to control emissions from hazardous waste incinerator facilities is a water quench to cause gas cooling and conditioning, followed by a high energy venturi wet scrubber for particulate removal, a counter-current or cross-flow packed tower absorber for acid gas removal, and a demister to reduce the visible vapour plume in the stack emissions (3).

Other devices that could be substituted into the gas cleaning process train include a wet or dry electrostatic precipitator, an ionizing wet scrubber, a tray tower absorber, a spray drier absorber and baghouse. These latter two when used together are termed "dry scrubbing" and represent more recent technology (26).

In the wet scrubbing methods, a caustic solution often is used to assist in the removal of halogen compounds from the exhaust gases. The resulting scrubber blowdown water stream requires appropriate treatment before discharge. In dry scrubbing technologies, lime slurry may be used in the spray drier absorber unit at a considerable cost savings over caustic. Dry scrubbing offers other potential advantages over wet scrubbing; included among these are (26):

- Exit temperature of gas leaving dry system baghouse will be above the saturation temperature, and therefore, there will not be a visible stack plume except during extreme weather conditions.
- A significant reduction of heavy metals contained in the flue gases is achieved by this system. The high degree of atomization of the lime slurry produces particles of essentially all sizes up to 100 microns. This enormous amount of surface acts to adsorb the bulk of the vapour phase heavy metals such as mercury, cadmium, arsenic and lead which are carried over in the gas stream. In addition, this mechanism also acts to improve the removal of incomplete products of combustion.
- The use of a baghouse for particulate removal provides a means of accommodating sustained overloading (with shorter cleaning cycles) and a means of dampening particulate excursions that might occur due to a voluntary high ash loading.
- The cake that forms on the bags contains residual lime which will continue to react with any residual acid gas that passes through the spray dryer absorber thereby providing a means of dampening occasional acid gas excursions.

Particular care must be taken in the design and operation of a dry scrubbing system to ensure that the upper operating temperature limits in the spray dryer absorber and baghouse are not exceeded.

Regardless of the types of emission control devices used in the incinerator, there is a need for continuous monitoring of the stack emissions for such parameters as temperature, particulates, oxygen, halogens, and oxides of sulphur and and nitrogen. This monitoring program is in addition to any measurements taken upstream for process monitoring and control purposes.

PERFORMANCE

The U.S. EPA has mandated that hazardous waste incineration in the United States must comply with the following performance standards:

- At least 99.99 percent destruction and removal efficiency (DRE) for each principal organic hazardous constituent (POHC) in the waste feed.
- At least 99 percent removal of hydrogen chloride from the exhaust gas if hydrogen chloride stack emissions exceed 1.8 kg/h.
- Less than a 180 mg/std m^3 of particulate emissions corrected to 7 percent oxygen in the stack gas.
- And in addition for wastes containing certain dioxins, furans and chlorinated phenols, at least 99.9999 percent destruction and removal efficiency for these compounds.

The results of numerous emission tests on the large number of hazardous wastes incinerators in United States have been summarized by Oppelt (3) and he has concluded among other things, that:

- Incineration is a demonstrated, commercially available technology for hazardous waste disposal. Considerable design experience exists and design and operating guidelines are available on the engineering aspects of these systems.
- Incinerators in most industrial processes employing hazardous wastes as a fuel can attain the RCRA destruction and removal efficiency requirements and the HCl emission limit.
- Certain incinerators have had difficulty achieving the RCRA particulate matter emission limit of a 180 mg/m^3. However, data suggest

that improved air pollution control technology or operating practices will enable these facilities to be upgraded to meet the standard.

- Based on current data, chlorinated dioxin and furan emissions are not significant for hazardous waste incinerators. The most hazardous dioxin isomer (2,3,7,8-TCDD) has not been detected in the emissions at the 17 facilities tested for these compounds. Levels of all polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran emissions from hazardous waste incinerators are approximately three orders of magnitude less than those reported for municipal waste incinerators.

SITE REQUIREMENTS

Aside from the considerations commonly employed when selecting any hazardous waste processing facility (geotechnical/hydrogeological, flooding, land stability, socio-economic issues, etc.), a hazardous waste incineration facility should be located in an airshed that allows for the effective and consistent dispersion of the stack emissions. In addition, the following utilities and infrastructure should be readily available:

- Vehicle access for delivery of wastes and reagents and removal of residuals if they are to be disposed elsewhere.
- On-site feed storage and solid residual storage areas.
- Availability of electricity, water and natural gas (if used as auxiliary fuel) services.
- Facilities to treat and dispose of scrubber/quench water.

In addition, sufficient concrete base pads or other prepared areas, and other essential features should be incorporated into a site on which is to be located a mobile/transportable thermal treatment facility.

MOBILITY AND TRANSPORTABILITY

Several mobile/transportable technologies have been developed and applied for the thermal destruction of hazardous wastes. Typically they have found wide application at U.S. Superfund site clean-up projects. Many other mobile/transportable technologies are still in varying stages of develop-

ment. Those which are commercially available in North America include (12)(16)(27)(28)(29)(30):

- Small rotary kilns - both mobile and transportable rotary kiln thermal treatment systems are available with thermal ratings from about 8,000 to 35,000 kJ/h (8 to 35 MMBTU/h) and capacities ranging from about 0.9 to 4.5 tonnes/h (1 to 5 tons/h) at 10 to 15 percent soil moisture content. These rotary kilns can handle many different types of wastes with the capacity of the kiln being an inverse function of the soil moisture content. Suppliers include ENSCO Environmental Services, Winston Technologies Inc., and DETOXCO Inc.

- Large rotary kilns - IT Corporation has constructed a transportable rotary kiln system called a Hybrid Thermal Treatment System (HTTS) with a nominal capacity of 56,000 kJ/h (56×10^6 BTU/h) for organics and 18 tonnes/h (20 tons/h) for soils. The system includes feed preparation, rotary kiln, secondary combustion chamber, gas quencher and scrubber, stack, wastewater treatment and residual ash handling components.

- Infrared conveyor furnace - A Shirco infrared conveyor furnace with a 3 tonne/h capacity at 10 to 15 percent soil moisture has been developed. The soil processing capacity of the furnace is strongly affected by both soil moisture and soil thermal content.

- Fluidized bed - Mobile/transportable fluidized bed incinerators are available for both the conventional bubbling bed technology (Waste-Tech Services) and the circulating bed technology (Ogden Environmental Services Inc.)

- Plasma arc pyrolysis - a mobile trailer-mounted plasma arc pyrolysis system has been developed by Pyrolysis Systems Inc. and Westinghouse Electric Corporation.

- Advanced Electrical Reactor - J.M. Huber Corporation has developed two mobile pilot scale versions of this technology.

- Supercritical Oxidation - MODAR Inc., has developed a mobile pilot scale system.

- Wet Air Oxidation - Zimpro Inc. has developed full-scale mobile skid-mounted units for hazardous waste treatment with nominal capacities of 38 L/m (10 USgpm).

For PCB destruction, the following mobile/transportable technologies are reported to be proven and available now for application:

TABLE 4-3: Capital Costs for Different Hazardous Waste Incinerators (After Bruner, 1987)

Incinerator Heat Release (Million BTU/h)	Installed Cost, (Million $)			
	Rotary Kiln	Fluid Bed	Fixed Hearth	Liquid Injection
5	3.0	3.5	0.5	0.8
10	4.5	5.0	1.2	1.0
25	8.0	8.0	2.0	1.8
50	12.0	13.0	NA	2.8
75	15.5	15.5	NA	3.5
100	18.5	20.0	NA	4.0

NOTES

- Costs are based on installation of a complete system outdoors, including ash-removal and air emission control equipment, electrical and instrumentation systems, and basic structure; no heat recovery. No engineering costs are included.
- NA: Not applicable.
- Costs expressed in 1987 U.S. dollars.

Name	Suitable for Processing PCB-Contaminated:			
	Large Bulky Solids	Size-Reduced Solids	Slurries	Liquids
Large Rotary Kilns	X	X	X	X
Small Rotary Kilns		X	X	X
Infrared Conveyor Furnace		X	X	X
Fluidized Bed		X	X	X
Plasma Arc				X

THERMAL DESTRUCTION COSTS

Costs for the thermal destruction of organic wastes depend on a number of factors including:

- Thermal content of the waste
- Type of waste (liquid, sludge, solid)
- Container holding the waste (bulk, drummed, etc.)
- Halogen content
- Moisture content.

Table 4-3 summarizes the approximate capital costs of different types of incinerators expressed in U.S. dollars (2).

In general, unit costs in current Canadian dollars for destruction of waste at stationary facilities are approximately (31):

- $0.33/L for "good quality" liquid organic waste.
- $0.66 to $1.66/L for more difficult to process waste such as certain solids and highly chlorinated organics.
- $4.50/L for drummed difficult to process wastes.

In one reference (28), the cost of treating contaminated soil using transportable rotary kiln incineration is reported to range from $135 to $450 per tonne. Another paper (12) reports that for the incineration of "lightly contaminated" soils at small (say 1000 to 5000 tonnes range) contaminated site cleanups, costs will be $450 to $900 per tonne; for medium sized sites, the treatment costs for lightly contaminated soils would vary from $180 to

$450 per tonne, and for large sites (say >30,000 tonnes), the cost would be from $90 to $360 per tonne depending upon the capacity of the equipment used and the soil moisture content. Cost of treating wastes using mobile fluidized bed combustion process technology is reported to be $540 to $1,350 per tonne (30).

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CHAPTER 5.0

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES

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PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES

INTRODUCTION

Physical/Chemical treatment processes encompass those processes which result in a physical and/or chemical change in the properties of the waste material. The nature of the change is such that it renders the waste less hazardous, or else makes the waste more amenable to subsequent treatment and detoxification processes.

Described below under separate headings are several physical treatment unit operations, chemical treatment unit operations, and physical/chemical treatment processes that are suitable for the treatment of hazardous wastes. With only a few exceptions, all of these unit operations and processes have been developed before hazardous waste treatment became a concern. They have been applied widely in the chemical processing, water and wastewater treatment industries. Consequently the technologies can be considered quite well developed although there still is room for innovative development and demonstration work, particularly for hazardous contaminant site cleanup projects.

PHYSICAL UNIT OPERATIONS

Physical unit processes result in a physical change in the state or phase of a waste material. This change may be effected by measures that increase the concentration of the waste material, by measures that cause the material to change from one thermodynamic phase to another, or by measures that separate the hazardous constituents of the waste from the carrying medium.

Stripping:

Stripping consists of a contacting system that provides for mass transfer of volatile components from a dilute solution stream into a gaseous phase. In general, if the Henry's Law Constant of the hazardous contaminant is greater

than about 3.0×10^{-3} atm-m^3/mole, then stripping can be an effective means of treatment. Typical examples of chemicals that can be stripped from aqueous solution are benzene, toluene, xylene, trichloroethane, and alcohols (1).

Air stripping can be accomplished in a number of ways:

- By means of counter-current packed towers in which the liquid phase (usually contaminated water) flows downward by gravity through a packed column while the gas phase is blown upward through the bed.
- By means of a counter-current tray column in which the liquid and gas phases again flow downward and upward respectively.
- By installing either diffused or mechanical aeration devices in a vessel containing the liquid to be treated.
- By causing a series of cascades of the liquid to be stripped.

Air stripping is generally applicable for solutions containing less than 1 percent of the contaminant to be stripped. Air stripping is suited to the removal of volatile organics, as well as the inorganic hydrogen cyanide and hydrogen sulphide molecules under acid conditions. Removal efficiencies varying from 50 to 90 percent or better are achievable depending on the design and operation of the process and the physical/chemical properties of the waste. Air stripping usually is not effective for low volatility organics, highly soluble compounds, metals and most inorganics (1).

Steam stripping uses steam to remove contaminants from liquids, dilute slurries and sludges. The steam can be added in many ways, but the two most common methods are by direct injection into the vessel containing the waste (a batch operation) or by means of a continuous tray column (a continuous operation) (2). Steam stripping often is applicable to a wider variety of wastes because wastes with contaminant concentrations as high as 20 percent can be treated. In addition, steam stripping is effective in removing organics of lower volatility as well as more complex organics such as phenols, ketones and phthalates. However it is not effective on water-miscible organics.

The off-gases from a stripping process likely will require some form of treatment such as carbon adsorption or incineration to render them non-toxic. Furthermore the aqueous phase also may require additional treatment.

Evaporation:

Evaporation is a unit operation in which thermal energy is applied to a liquid solution or slurry in order to vapourize the more volatile components of the mixture. Depending upon the type of waste under consideration, evaporation will concentrate the hazardous components either in the vapour phase or in the liquid/sludge/solid phase. Evaporation usually is used as an initial processing step to concentrate hazardous constituents prior to further treatment.

There are several types of evaporation equipment on the market. These include:

- Agitated thin-film evaporators
- Scraped surface evaporators
- Kettle evaporators
- Tubular evaporators
- Vapour compression evaporators

In addition to the above equipment types, evaporation ponds are considered appropriate technology for disposal of treated aqueous-based wastes in arid climates.

The agitated thin-film evaporator has found wide acceptance in the waste solvent recycling industry and is applicable to wastes with low solids content (1). The scraped surface evaporator is also used for the recovery of spent solvents containing appreciable concentrations of suspended solids and sludges (3). Due to the wide variety of contaminants often encountered in waste streams, scaling or fouling of evaporator surfaces is a common problem (4). The other types of evaporators generally do not find wide application for hazardous waste treatment.

In the past, evaporation ponds have been used in arid climates to evaporate untreated aqueous-based wastes. However this method has fallen out of favour due to concerns about volatile organic emissions to the ambient air

in the vicinity of the ponds and pond leakage with subsequent potential for groundwater contamination. Nevertheless, evaporation ponds with suitable liners are an acceptable means of disposing of treated aqueous-based wastes in arid climates.

Distillation:

Distillation is the separation of two or more components of a liquid mixture by vapourizing the mixture and separately recovering the vapour and the residue. In simple or batch distillation, there is one equilibrium present between the liquid and the gas phases and a crude separation of the feed stream occurs. The condensate will be richer in the more volatile components than will the bottoms. In multi-stage or fractional distillation, a series of liquid-vapour equilibria is achieved inside a vertical tower and the final overhead product is much more rich (pure) in low boiling components than can be achieved with a simple distillation unit (2)(3).

Distillation is applicable to relatively concentrated waste streams containing acetone, alcohol, chlorinated organics, ketones and a variety of non-halogenated hydrocarbon solvents. Distillation generally is not suited to processing liquids with high viscosities at high temperature, liquids with high solids concentrations, polyurethane, and most inorganic compounds (1). The still bottom residues generally can be directed to an incinerator for disposal.

Solvent Extraction:

Solvent extraction consists of contacting a waste material with solvent selected specifically to dissolve the hazardous contaminants in the waste. There are two general types of solvent extraction processes: liquid-liquid and solid-liquid. In the former, the contaminant (solute) is extracted from one liquid phase and transferred to the other liquid phase (the extract). In the latter, the contaminant is extracted from the solid phase and transferred to the liquid phase (the extract). In either case, the contaminant is extracted or dissolved into the phase in which it is preferentially more soluble (or miscible). The treated effluent stream from which the solvent

is extracted is termed the raffinate. For this technique to be effective, the extraction solvent must be immiscible in the liquid and differ in density so that gravity separation is possible and there is a minimal contamination of raffinate with the solvent (3).

The following waste types and solvents have been employed (1):

Waste Type	Compound
Metal cations	Weak acids, reducing agents, or chelating agents (EDTA and citric acid)
Anions (arsenic, selenium)	Water with oxidizers (H_2O_2)
Organics (insoluble)	Organic solvents (alcohols, alkanes) or water with surfactants
Organics (soluble)	Water only or water with surfactants

Equipment used in solvent extraction usually consists of a series of multi-stage mixing and settling operations in which the feed and the solvent streams travel counter-current to one another (5). A number of customized excavated soil washing and in-situ soil flushing solvent extraction techniques have been developed for remedial measures at hazardous waste cleanup sites (1).

Filtration:

Filtration is a widely used unit operation that can accomplish one of two objectives:

- Removal of suspended solids from a fluid by passing the fluid through a bed of gravel or porous material.
- Dewatering of sludges and soils.

Equipment used for the former objective includes sand and anthracite gravity or pressure filters, and leaf or candle filters using diatomaceous earth as a pre-coat and body feed medium.

A variety of equipment is available to accomplish the latter objective, including vacuum drum filters, vacuum belt filters, belt press filters, plate and frame filter presses, and diaphram filter presses. Depending on the nature of the solids to be dewatered, conditioning chemicals such as lime, iron salts, or polymers may be required to promote effective dewatering. Filtration is applicable to the dewatering of almost any sludge encountered in the hazardous waste processing industry.

Phase Separation:

Phase separation involves the separation of solid/liquid and liquid/liquid suspensions with different specific gravities. It is a well established unit operation and numerous manufacturers market a wide variety of phase separation equipment in different sizes and capacities. This equipment may be grouped into three general categories:

- **Oil Separation** - which involves de-emulsification and coalescence of oil dispersions. Usually the liquid is passed through a bank of parallel plates separated by approximately 2 to 5 cm and contained in a treatment vessel. The quiescent laminar flow profile caused by passage of the liquid between the plates promotes contact of dispersed oil droplets and consequent coalescence. The coalesced oil floats to the top of the vessel and is removed by a skimming or decanting mechanism. Heating and/or chemical additives may be used to promote improved coalescence. For oil separation to occur by this means, there must be density difference between the oil and the carrying liquid.

- **Centrifugation** - wherein an oil/liquid dispersion or a solid/liquid suspension is subjected to intense centrifugal force to cause a separation of the two phases. As above, there must be a density difference between the two phases in order for the separation to occur.

- **Dissolved Air Flotation** - wherein air is dissolved under high pressure in either the feed stream or more preferrably in a recycled stream of the treated effluent from the dissolved air flotation unit. As the pressurized stream enters the treatment vessel, the pressure is released and fine bubbles form from the supersaturated solution, much in the same way that bubbles form when the top is removed from a carbonated beverage bottle. These bubbles attach themselves to dispersed oil and/or particulate matter and cause them to rise to the surface of the vessel where they are removed by a skimming mechanism. Chemicals are sometimes added to change the surface properties of the emulsion or suspension in order to enhance the effectiveness of the flotation process.

Wastes that can be treated by these phase separation techniques include immiscible oily liquids dispersed in water, waste containing suspended solids, waste containing hydrophobic compounds, and two phase liquids. The technique is not suited to dissolved organic and inorganic contaminants (1).

Activated Carbon Adsorption:

Adsorption is a surface phenomenon which relies on the removal of soluble molecules from solution by means of bonding onto a particulate substrate. Activated carbon particles have a very high surface-to-volume ratio (500 to 1,400 m^2/g) and therefore are very effective as an absorbent (1). There are two main types of carbon contacting equipment - packed bed pressure or gravity downflow carbon filters, and expanded bed upflow carbon contacting columns. A third carbon contacting technique involving the addition of powdered activated carbon to an aqueous stream while it is passing through another treatment process is also used (3). Activated carbon adsorption is considered to be a proven process and has had wide application in the water, wastewater and chemical processing industries for a number of years.

In general, activated carbon adsorption is suited to dilute (less than 1,000 mg/L) aqueous solutions of non-polar, high molecular weight halogenated and non-halogenated organic wastes. Branch chain molecules are more adsorbable than straight molecules. It is also suited for the removal of organic nitrogen compounds and chelated heavy metals. It has limited application for the removal of low molecular weight organics, highly polar and highly soluble compounds. Pre-treatment of the waste may be necessary if it contains oil concentrations in excess of 10 mg/L and suspended solids concentrations about 50 to 500 mg/L (1)(2)(3).

Activated carbon has a finite capacity to adsorb wastes and, once saturated, must be either replaced or regenerated. Regeneration can be accomplished by means of steam stripping or thermal treatment using a rotary kiln, multiple hearth or fluidized bed furnace. Economic considerations indicate that if carbon consumption is greater than about 180 kg/d, on-site regeneration of the spent carbon becomes attractive (3).

Ion Exchange:

Ion exchange is a separation technique which removes ionic species from solution by interchanging reversibly adsorbed ions between the exchanger (resin) and the solution (waste) (6). This exchange occurs because any divalent and trivalent toxic metal anions or cations in the waste have greater affinity for the charged sites on the surfaces of the resin than the weakly-held monovalent anions or cations (1). Ion exchange is an established technology that is continuing to find wider applications by the development of improved resins with higher exchange capacities and resins that are capable of selectively removing specific groups of ions. Equipment used in ion exchange generally consists of flow-through packed bed contacting columns containing a synthetic organic resin material in the form of beads. Two types of resins are produced - anion exchange resins which remove positively charged ions from solution and cation exchange resins which remove negatively charged ions.

Wastes that are suited to ion exchange treatment include: dilute solutions (say less than 2,500 mg/L max.) of the following (1)(6):

- Metallic anions and cations such as $Cr_2O_7^{-2}$, SeO_4^{-2}, AsO_4^{-2}, Ni^{+2}, Cd^{+2}, and Hg^{+2}
- Inorganic ions such as halides, sulphates and cyanides
- Organic acids such as carboxylic, sulphonics and some phenols, and,
- Organic bases such as amines.

In order to avoid fouling of the resins, it is advisable that the feed stream be filtered for particulate and oil removal, and that it not contain oxidizers such as chlorine, or permanganate.

Membrane Separation:

Membrane separation operations employ a semi-permeable membrane to separate dissolved and/or very finely dispersed solids from a liquid phase. While this technology has been in existence for several years, it is undergoing continuing development with research on new and improved membrane materials.

The two general types of membrane operations suited to hazardous waste treatment include reverse osmosis and electrodialysis.

In reverse osmosis, solutes (contaminants) are removed from solution (the solvent) by forcing the solvent molecules through the microscopic pores of a semi-permeable membrane using a pressure sufficient to overcome the osmotic pressure of the solution. As the solvent passes through the membrane, the larger organic and inorganic molecules remain behind and a relatively solute-free product stream is produced. No membrane has been developed as yet that can withstand chemical attack by the wide variety of contaminants found in hazardous waste; however, membranes can be selected for application to treat specific hazardous waste streams such as spent metal plating solution wastes, and the treatment of organic contaminated leachates and groundwaters from landfill and spill sites.

In electrodialysis systems, an electrical potential is applied across a semi-permeable membrane immersed in solution to provide a driving force for ions to pass through the membrane. This is considered to be an emerging technology and might have limited application to specific hazardous waste streams.

Membrane operations require pre-treatment steps including filtration and sometimes chemical addition (for pH adjustment, etc.) to avoid damage to the membrane. In addition, the reject stream containing the more concentrated contaminants must be subjected to further treatment.

CHEMICAL UNIT OPERATIONS

Chemical unit operations are those that involves some form of chemical change to the waste that renders it either less hazardous or makes it amenable to further treatment.

Reduction-Oxidation (Redox) Treatment:

Reduction-oxidation reactions result in a change of the oxidation states of the reactants - the oxidation state of one reactant is raised while that of

the other reactant is lowered. Equipment requirements include a mixed reaction vessel, reagent chemical storage and metering system, and vented gas scrubbing if there is a risk of hazardous vapours evolving from the redox reactions. The equipment configuration may be in either a batch or a continuous flow-through mode. Oxidation-reduction potential (ORP) electrodes can be used to monitor the progress of the reaction.

Redox treatment is considered a proven and well established technology and has been used in the chemical processing industry for decades. Typical wastes that can treated by redox technology include (1):

By Oxidation	**By Reduction**
Benzene	Hexavalent Chromium
Phenols	Mercury
Most Organics	Lead
Cyanide	Silver
Arsenic	Chlorinated Organics
Iron and Manganese	Unsaturated Hydrocarbons

Care must be taken so that unwanted side effects do not occur, for example:

- If trivalent chromium is present in a waste undergoing oxidation treatment for other constituents, the trivalent chromium also will be oxidized to the much more toxic pentavalent state.
- Treatment of solids in-situ to precipitate metals may result in an alteration of the organic structure and hence the adsorption capacity of the soil, and in the formation of hydroxides that can cause a marked decrease in soil permeability.
- Redox chemical treatment may not be cost effective when treating concentrated wastes. Other forms and combinations of physical, chemical or thermal operations may be more appropriate.

Reagents commonly used in redox treatment process include (1)(7):

Oxidizing Agents	Reducing Agents
Ozone	Ferrous Sulphate
Hypochlorite	Sodium Sulphite
Hydrogen Peroxide	Sulphur Dioxide
Chlorine	Iron (II)
Potassium Permanganate	Aluminum
UV/Ozone	Zinc
	Sodium Borohydrate

Neutralization:

Neutralization is a chemical processing step whereby an acid (pH <<7) is blended with an alkali (pH>>7) to achieve a final product that is in the neutral pH range (say pH 5 to 9). Equipment used for neutralization includes blending tanks, mixers, feed pumps and chemical storage and metering systems to add the neutralizing chemicals (usually lime or sodium hydroxide for neutralization of acids, and sulphuric acid for neutralization of alkalis). Neutralization is a well established process that has been used in the chemical industry for decades.

Neutralization can be done in either batch or continuous flow-through modes. If a continuous flow system is used, then it is desirable to conduct the neutralization reaction in two vessels in series - in the first vessel, sufficient neutralization reagent is added to achieve an approximate degree of neutralization and in the second vessel, additional chemical is added to "touch-up" the neutralization reaction and achieve the desired pH level.

Quite often, chemical savings can be realized by using waste acids and waste alkalis together in a mutual neutralization reaction. If sludges or slurries are present, additional time and/or neutralizing agent may be required to allow for a slow rate of reaction or to overcome the buffer capacity of the solids. Sometimes a precipitate is formed during a neutralization reaction. In any event, neutralization usually is one step in an overall physical/chemical treatment system.

A number of precautions should be taken when designing and operating neutralization operations:

- Particular care must be taken in the choice of materials for the vessels and other equipment that will come in contact with the wastes and neutralizing agents. Many of these are likely to be quite corrosive.

- Excessive heat might evolve during the course of the neutralization reaction and care must be taken to ensure that either the reactants are blended together at a controlled rate or that the heat is extracted from the system such that no harm to the equipment or operating personnel occurs.

- The neutralization reactors should be covered and vented through a scrubbing device as toxic gases such as ammonia, hydrogen cyanide and hydrogen sulphide can be released from solution during neutralization reactions.

Precipitation:

Chemical precipitation is a common means of removing soluble metals and other dissolved solids from wastewater streams. Chemical precipitation usually is combined with other steps such as:

- Flocculation - whereby gentle mixing of the chemically-precipitated wastewater is performed to promote contact of the precipitated particles with one-another so that the particles grow in size and can be separated by gravity sedimentation.

- Sedimentation - wherein the precipitated and flocculated solids are settled by gravity to concentrate them into a sludge.

- Filtration - wherein the settled sludge is dewatered for subsequent further processing or landfilling as may be appropriate.

Chemical precipitation has been a long established process in the chemical industry and has been used in the water, wastewater and certain industrial waste treatment areas for some time.

The common chemical agents typically added to a waste stream to precipitate metals are lime, magnesium oxide and sulphides. The first two result in an insoluble metal hydroxide precipitate while the last one results in an insoluble metal sulphide precipitate. The presence of chelating agents such as EDTA and citrate can have an adverse effect on the effectiveness of the precipitation reaction (6).

Dechlorination:

Since the concern over the toxicity of polychlorinated biphenyls (PCBs) has arisen over the past several years, a few companies have developed chemical dechlorination technology that can remove the chlorine atoms from PCB molecules. This phenomenon is accomplished by contacting metallic sodium plus a proprietary constituent (such as polypropylene glycol) with the PCB-contaminated material. The chlorine is displaced by the polypropylene glycol to form sodium chloride and a substituted organic polymer. The developers of the various processes all use different proprietary organic reagents in conjunction with the sodium to accomplish the chlorine substitution task (1)(3)(8)(9).

Dechlorination has been applied successfully for the treatment of PCB-containing transformer oils at several sites. It is effective for wastes containing less than 5,000 ppm of PCBs. Above this concentration, incineration may become more cost-effective. Treated oils usually contain less than 2 ppm of PCBs and the oil usually can be re-used for some purpose. The moisture content of the waste is critical as this can have an adverse effect on the stability of the reagents and the effectiveness of the process. If moisture is present, the waste should be pre-treated to remove it (1)(7)(8).

Experimental work is being done to dechlorinate halogenated hydrocarbon containing soils using these processes; however, the work is still very much in a developmental stage (1)(8).

PHYSICAL/CHEMICAL TREATMENT PROCESSES

The preceeding two sections of this Chapter have reviewed separately the physical and chemical unit operations that have been used for the treatment of hazardous wastes. In this section, the various combinations of these unit operations are presented that form generic processing trains representing complete treatment schemes for several different types of hazardous wastes. The material presented herein has been extracted from the paper by Warner and Olexsey (10). The reader is referred also to block diagram sche-

matics of other hazardous waste treatment processes which are outlined by Cheremisinoff (7). Incorporated in the processing trains for the sake of completeness are references to processes covered in other Chapters of this report such as incineration and secure repositories.

Illustrated on the next seven pages are schematic diagrams of generic treatment processes for the following waste types:

- Process A - Aqueous treatment of inorganic wastes (Figure 5-1)
- Process B - Aqueous treatment of wastes with metals and trace organics (Figure 5-2)
- Process C - Aqueous treatment of dilute organic wastes (Figure 5-3)
- Process D - Recovery/reuse of halogenated and non-halogenated solvents (Figure 5-4)
- Process E - Incineration of combustible sludges, solids and liquids (Figure 5-5)
- Process F - Treatment of heavy metal sludges (Figure 5-6)
- Process G - Recovery and treatment of concentrated and dilute oils (Figure 5-7).

Note that many of the same unit operations appear repeatedly in each of these generic processes. Thus it is important when designing a physical/chemical treatment system, that considerable flexibility and redundancy be incorporated into the piping, pumping, chemical feed, tankage and control systems to permit adaptation of the available equipment to process the variety waste types to be handled by the facility.

SITE REQUIREMENTS

The considerations commonly employed when selecting any hazardous waste processing facility such as geotechnical/hydrogeological, flooding, land stability, socio-economic issues, etc., are generally applicable to a physical/chemical hazardous waste treatment plant. In addition, the following utilities and infrastructure should be readily available.

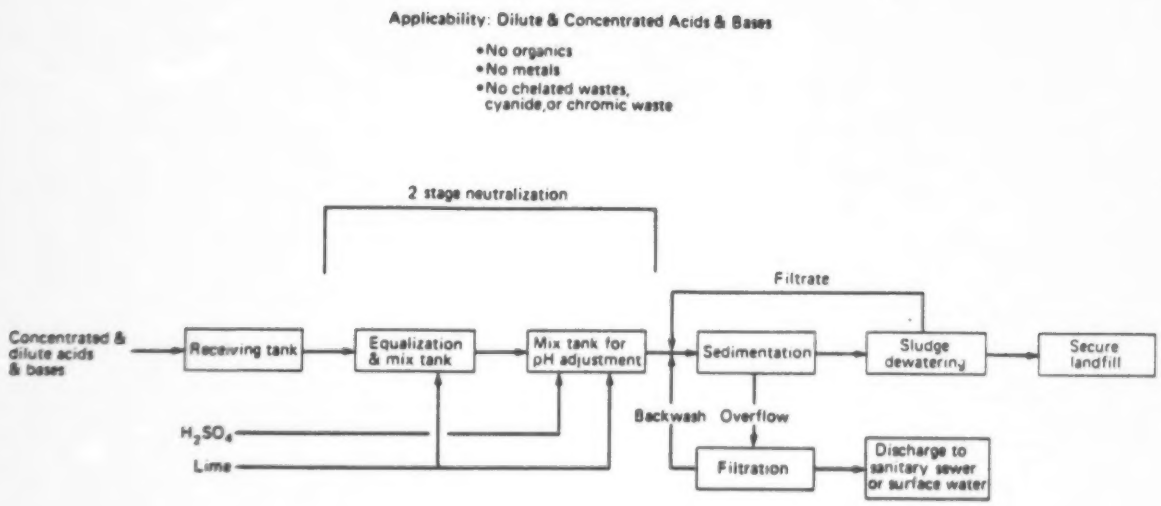

FIGURE 5-1:

Process A - Aqueous Treatment of Inorganic Wastes
(After Warner & Olexsey, 1986)

Applicability: Dilute and Concentrated Acids and Bases, Inorganic

- With trace organics(chelated wastes, oils, grease, solvents)
- Metals can be present
- Handle chelated waste, cyanides, chromic acid separately

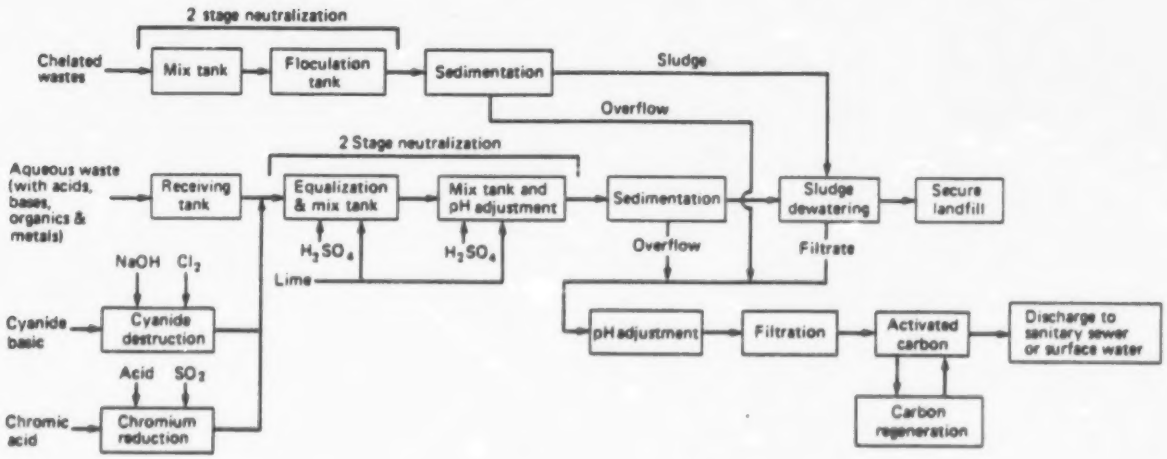

FIGURE 5-2

Process B - Aqueous Treatment of Wastes with Metals and Trace Organics
(After Warner & Olexsey, 1986)

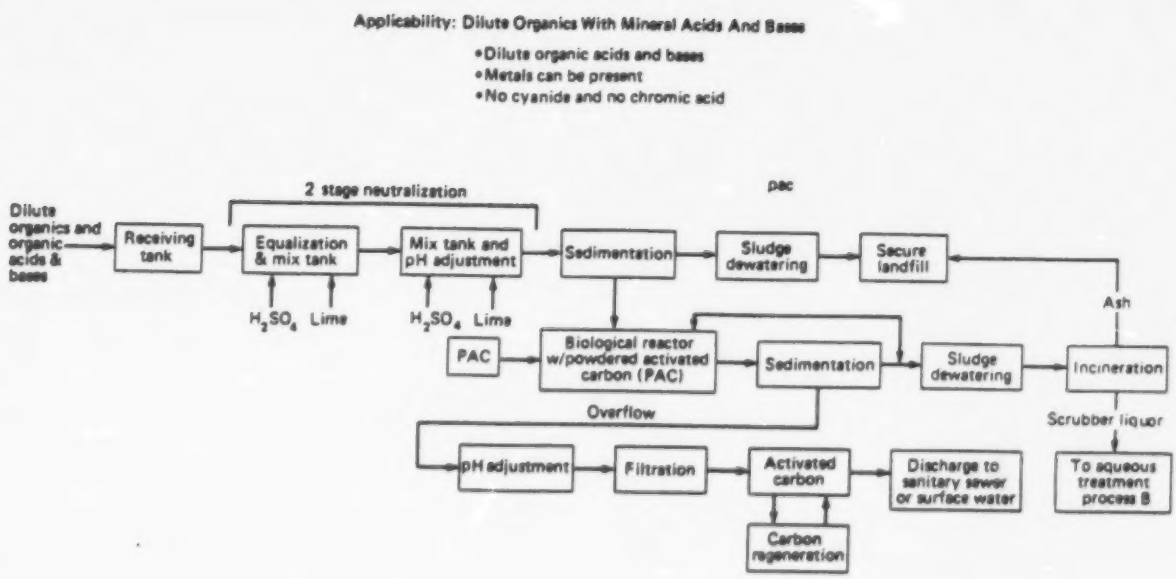

FIGURE 5-3

Process C - Aqueous Treatment of Dilute Organic Wastes
(After Warner & Olexsey, 1986)

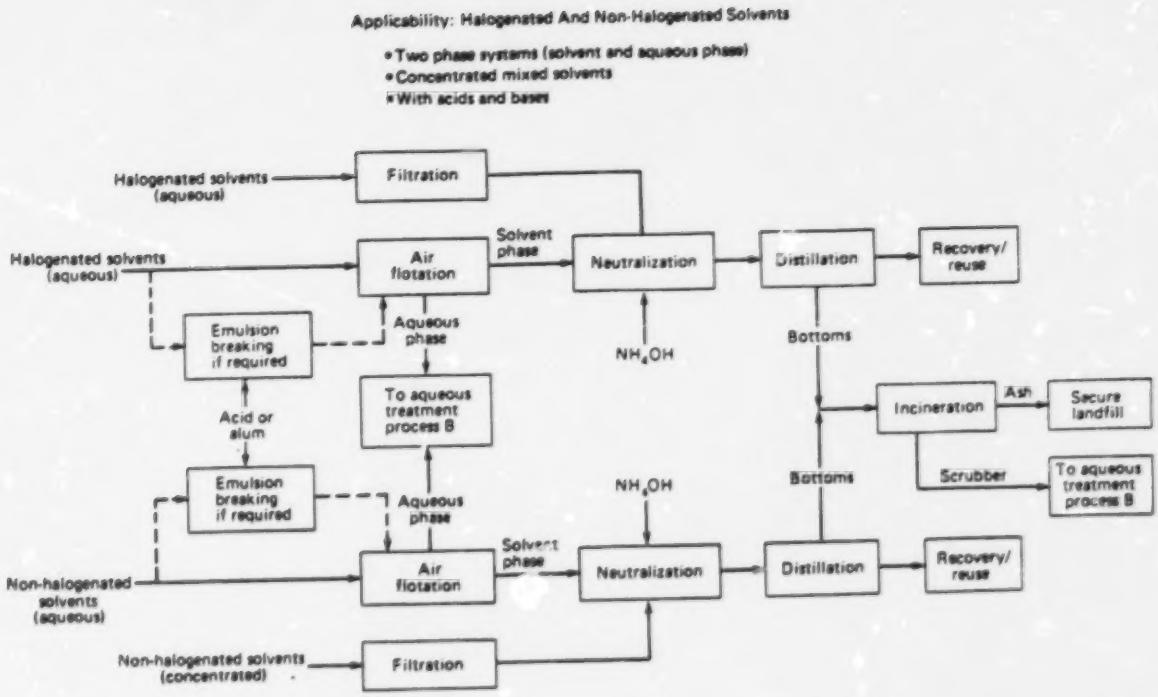

FIGURE 5-4

Process D - Recovery/Reuse of Halogenated and Non-halogenated Solvents
(After Warner & Olexsey, 1986)

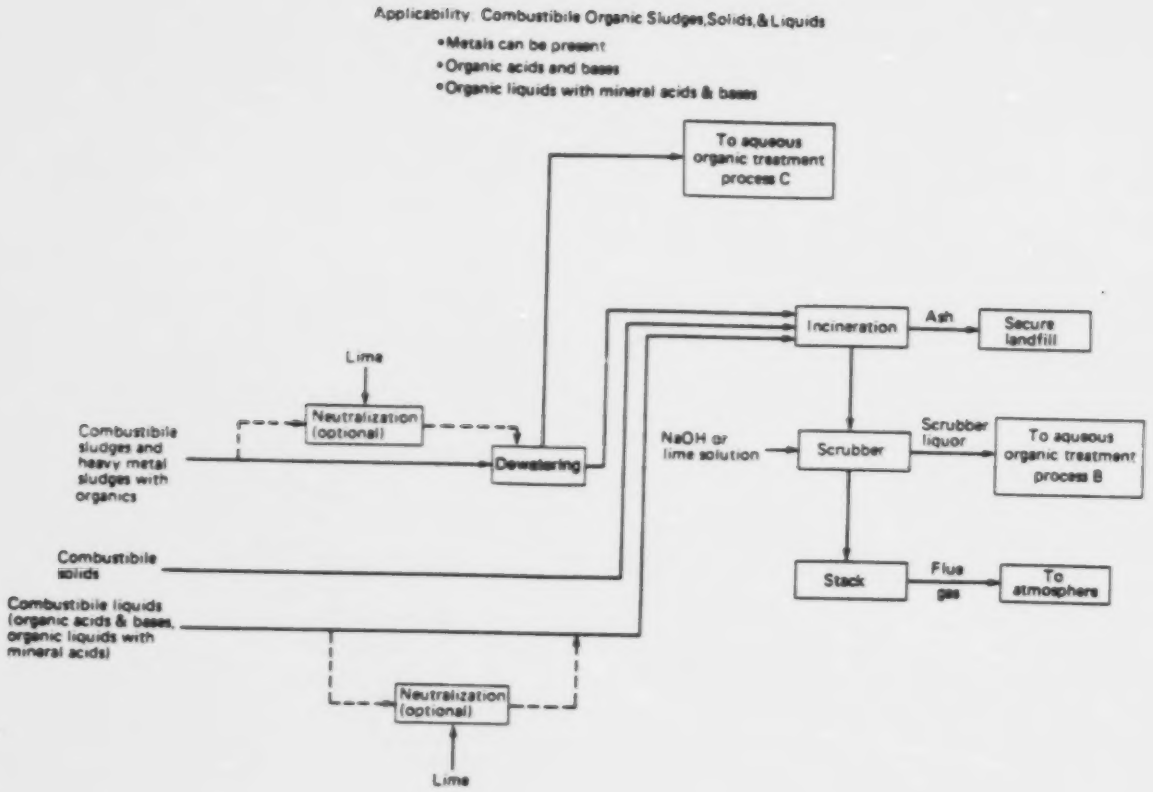

FIGURE 5-5

Process E - Incineration of Combustible Sludges, Solids and Liquids
(After Warner & Olexsey, 1986)

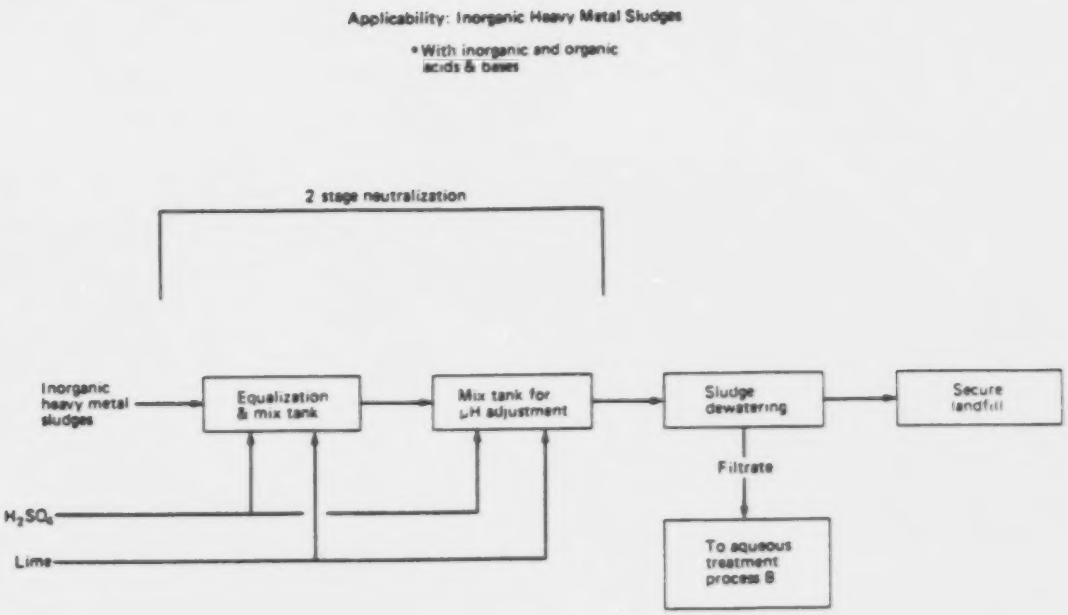

FIGURE 5-6

Process F - Treatment of Heavy Metal Sludges
(After Warner & Olexsey, 1986)

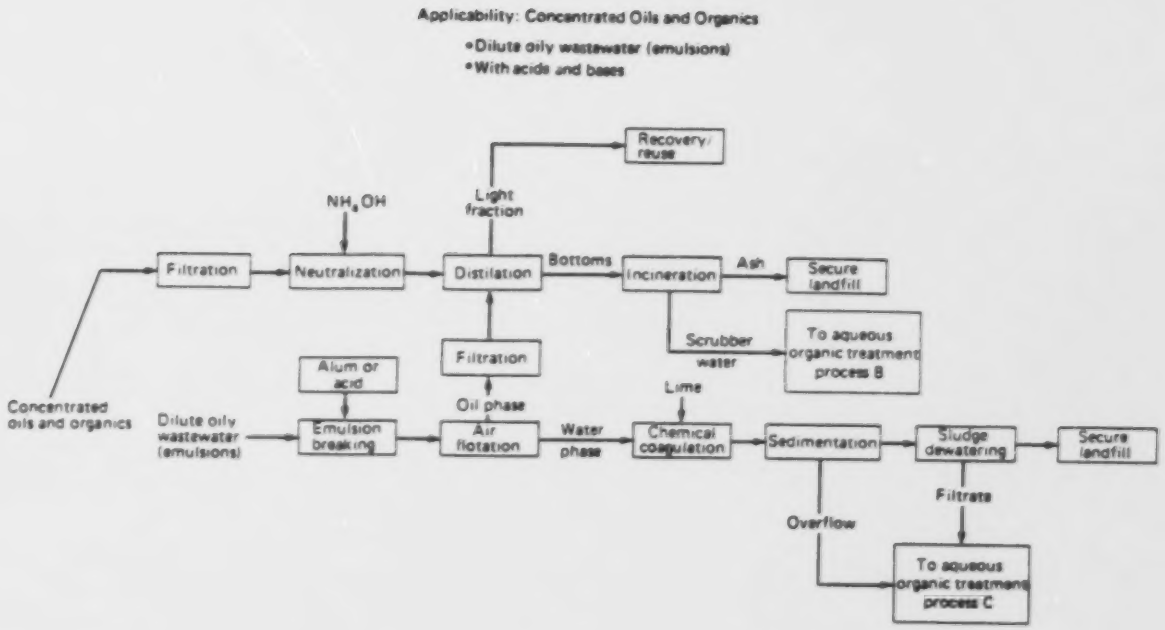

FIGURE 5-7

Process G - Recovery and Treatment of Concentrated and Dilute Oils
(After Warner & Olexsey, 1986)

- Vehicle access for delivery of wastes and reagents and removal of residuals if they are to be disposed of elsewhere.
- On-site feed storage and solid residual storage areas.
- Availability of electrical and water services.
- Suitability of site for using an appropriate means of disposing of treated wastewaters.

Sufficient concrete base pads or other prepared areas, and other essential features should be incorporated into a site on which is to be located a mobile/transportable physical/chemical treatment facility.

MOBILITY AND TRANSPORTABILITY

Essentially all of the physical and chemical unit operations reviewed in this Chapter can be designed and constructed in small enough sizes to permit mounting on mobile and/or transportable trailers.

Several equipment suppliers and waste management firms have constructed mobile facilities incorporating such unit operations as neutralization, precipitation, centrifugation, filter dewatering, distillation, carbon adsorption, etc., into generic processing plants. Other firms offer services to custom-build mobile treatment systems for application to particular waste types. In addition, at least four firms in North America offer PCB dechlorination services using mobile trailer-mounted equipment (1)(11)(12)(13)(14)(15)(16).

The U.S. EPA has constructed transportable physical/chemical treatment systems that are maintained by the EPA's Environmental Emergency Response Unit (17). These systems include the following trailer-mounted process trains:

- chemical addition, reactor, flocculation chamber, inclined tube settler and tri-media filter
- reverse osmosis
- flocculator, sedimentation, filtration, carbon adsorption.

PHYSICAL/CHEMICAL TREATMENT COSTS

The costs associated with the construction and operation of physical/chemical treatment systems will be a function of several factors including; but not necessarily limited to, the following:

- the individual constituents and their respective concentrations in the waste stream
- the type of physical/chemical unit operation or processing combinations of various unit operations required to treat the waste
- the quantity of waste available for processing
- opportunities for using an additional waste stream as a reactant when processing a given waste.

Information presented later in Chapter 8.0 of this report includes unit processing cost ranges derived from various literature sources for the different physical/chemical treatment technologies reviewed in this Chapter. The costs represent capital replacement plus operating and maintenance costs. They do not include either residue disposal costs or any credit for the recovery and sale of re-useable components from the waste stream. The unit processing cost ranges are as follows:

- Low - <$250 per tonne
- Medium - $250 to $750 per tonne
- High - >$750 per tonne

The approximate unit processing costs for the various physical/chemical unit operations are as follows:

Physical Unit Operation Costs

Stripping	- Low to Medium
Evaporation	- Medium to High
Distillation	- Medium
Solvent Extraction	- Medium to High
Filtration	- Low
Phase Separation	- Low
Activated Carbon Adsorption	- Medium
Ion Exchange	- Medium
Membrane Separation	- Medium

Chemical Unit Operation Costs

Redox	- Medium to High
Neutralization	- Low
Precipitation	- Low
Dechlorination	- Medium to High

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PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES

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CHAPTER 6.0

IMMOBILIZATION TECHNOLOGIES

CHAPTER 6.0
IMMOBILIZATION TECHNOLOGIES

INTRODUCTION

The main objective of the technologies reviewed in this Chapter is to decrease the mobility of hazardous wastes in the environment. Immobilization technologies refer to processing steps for individual waste streams that either chemically or physically render them into some sort of solid form from which the toxic and hazardous constituents are essentially non-leachable (or leachable at a very low rate).

There have been a variety of immobilization technologies developed over the past 10 to 20 years for application to hazardous wastes. In general, they accomplish either one or both of the following tasks:

- React with hazardous leachable contaminants in the waste to retain them within the structural matrix of the waste.
- Increase the dimensional stability, structural integrity and load bearing capacity of the waste so that it is more amenable to handling and placement in a waste repository.

In many of these processes, some degree of volume increase will occur due to the addition of reagents or binding chemicals. Typically this volume increase can vary from 10 to 50 percent and sometimes can be as much as 100 percent or more.

For purposes of this technology review, immobilization technologies have been divided into three generic groupings: pozzolanic, binding and encapsulation technologies. These are discussed under individual headings below. Much of this technology is proprietary. Not all technologies are suited to all types of wastes. Therefore it is recommended that bench testing be done on individual waste streams to determine the specific reagent quantities, addition and blending rates, and setting times that are required to achieve the desired result from a given waste stream.

POZZOLANIC TECHNOLOGY

Pozzolanic technologies use either Portland cement, lime, silicates, cement-kiln dust, fly ash, blast furnace slag, or some combination thereof as additives for aqueous wastes and sludges to precipitate metals and result in a solidified relatively impervious waste mass. The process is particularly effective for wastes containing metals because the high pH of the waste mixture tends to convert most of the multivalent cations into insoluble hydroxides or carbonates and these are retained in the solidified matrix. Soluble ions such as sodium, potassium, chloride, phosphate, sulphate, arsenate, etc., are not well retained in the cemented matrix and will tend to leach. In addition if such soluble inorganics, or if oils or other organic materials are present, they can interfere with the setting and curing of the cement-based reagents - at best acting as retardants or at worst, completely preventing solidification (1)(2)(3)(4).

The equipment used in pozzolanic techniques is commonly available in the cement processing industry. Costs for immobilization of wastes using pozzolanic technologies can vary widely from about $0.03/L to $0.25/L in Canadian dollars depending on the type and amount of chemical additives required to accomplish the reaction (2).

The pozzolanic techniques offer a number of advantages including (2)(4):

- Widespread availability of additives at a reasonable price.
- The techniques of cement mixing are well-developed and equipment is generally readily available.
- Strength, permeability, dewaterability and other significant characteristics of the final product can be controlled by appropriate adjustment of the reagents.
- Good long term stability both physically and chemically.
- The technology is well-developed and has been widely applied in the hazardous waste treatment industry.

The disadvantages of this technique include:

- Not applicable to all types of wastes - may require pre-treatment of wastes to remove soluble ions, oils and other organics.
- The cement and other additives can add considerably to the weight and bulk of the final product requiring disposal in a repository.

BINDING TECHNOLOGY

There are two general categories of binding technologies - organic polymer techniques and thermoplastic techniques. Both systems effectively "bind" the waste in a physical sense by surrounding the waste particles and preventing their exposure to environmental factors that would cause migration of the waste. Essentially, they can be considered "micro-encapsulation" techniques.

Organic polymer techniques originally were developed to solidify wastes for transportation. The most development work has been done on an urea-formaldehyde system wherein a monomer is thoroughly mixed with the waste in a blending drum after which a catalyst is added that gradually initiates a polymerization reaction. Usually, the polymerized material does not combine chemically with the waste; rather a spongy mass forms that traps the solid particles and permits some liquids to escape. While this technology appears to possess considerable potential for non-aqueous wastes such as halogenated and non-halogenated hydrocarbons, pesticides, etc., it has a number of drawbacks, including (2):

- Most organic systems are solvent-based and usually hydrophobic in nature. Therefore as reagents when dealing with aqueous-based wastes, these organics must be formulated as emulsions. This may or may not be feasible and/or effective.
- Organically bound wastes may have questionable long term stability in the presence of such ambient environmental factors as microorganisms and ultraviolet light.
- Costs are relatively high and begin at approximately $0.15/L as a minimum for easily bound wastes.

Thermoplastic techniques using such materials as bitumen, paraffin or polyethylene also have been used as binders for waste materials. This tech-

nology was originally developed for use on radioactive wastes. The process initially involves drying of the waste to remove moisture, then mixing it with bitumen or some other thermoplastic material at temperatures (100°C in a drum, then allowing the mixture to cool and solidify. The bitumen is usually added in a ratio of 1:1 to 1:2 (bitumen:waste). The technology is suited to many types of wastes; however, organic solvents and oxidizers cannot be processed in this fashion. In addition, compounds that dehydrate at the elevated mixing temperature (such as sulphates) can cause undesirable swelling and subsequent fracturing of the fixed product mass if it later becomes exposed to water.

In both of these binding technologies, costs tend to be relatively high and, as other cheaper process alternatives are generally available for most wastes, they have not found wide application in the hazardous waste management field.

ENCAPSULATION TECHNOLOGY

Considerable development work has been done by TRW Corporation (3)(4) on an encapsulation or jacketting technique for hazardous solid wastes. The technique involves the following steps:

- Thorough drying of the waste to eliminate moisture.
- Blending an acetone solution of 1,2-polybutadiene binder into the waste in an amount of about 3 to 4 percent by weight of the waste mass.
- Placement of the waste in a mold and heating to approximately 120°C to 200°C under slight mechanical pressure to produce fusion of the waste. The fused blocks typically weigh 360 to 480 kg (800 to 1,000 lbs).
- Remove from mold and fuse a 3.5 mm coating of polyethylene to the outside of the block.

The process is relatively expensive and consequently has not found wide application in the field of hazardous waste management. It would be most suitable for hazardous solid waste or sludges that are particularly toxic and not amenable to further treatment.

VITRIFICATION TECHNOLOGY

Techniques have been developed to render hazardous granular solids into a relatively inert and non-leachable glassy solid mass. Some of the early work in this area was done in the 1950's and 60's at Atomic Energy Canada Limited's Chalk River facility wherein small quantities of solid wastes were heated beyond their melting point, poured into spherical molds, and upon cooling, formed fused spherically-shaped glasslike masses.

More recently, Battelle Memorial Institute has developed an in-situ vitrification process for dealing with contaminated soils at remedial cleanup sites (7). In this process, electrodes are driven into the ground to form a square grid pattern area throughout the zone of contamination. Once the electrodes are in place, a conductive mixture of flaked graphite and glass frit is placed in 5 cm deep trenches connecting the electrodes in an "X" pattern. Voltage is applied to the electrodes and resistance heating of the contaminated soil occurs, commencing with the melting of the graphite/glass frit mixture, and proceeding eventually to the melting of the soil between and around the electrodes. Organic contaminants contained within the soil are pyrolyzed and volatilized; rise to the surface; are oxidized in the hot atmoshpere immediately above the surface; and are captured in a hood mounted over the processing area and directed to an off-gas treatment system for contaminant removal before discharge to the atmosphere. Once the desired zone of contamination has been melted, the power supply to the electrodes is turned off and the molten soil is allowed to cool into a dense vitrified mass. The cooling phase may take several months.

SITE REQUIREMENTS

The considerations commonly employed when selecting any hazardous waste processing facility such as geotechnical/hydrogeotechnical, flooding, land stability, socio-economic issues, etc., are generally applicable to an immobilization hazardous waste treatment plant. In addition, the following utilities and infrastructure should be readily available:

- Vehicle access for delivery of wastes and reagents and removal of residuals if they are to be deposited elsewhere.

- On-site feed storage area and immobilized product repository.

- Availability of adequate electrical and water services. Also availability of a heat source (say natural gas, etc.) if certain themoplastic binding or encapulation technologies require it.

Sufficient concrete base pads or other prepared areas should be incorporated into a site on which is to be located a mobile/transportable immobilization hazardous waste treatment plant. Often it is convenient to locate the final repository of the immobilized wastes nearby, particularly when pozzolanic technologies are employed. In this case, site constraints usually associated with such a repository should be considered. These constraints are discussed more fully in the next Chapter.

MOBILITY AND TRANSPORTABILITY

There are several firms which market mobile technologies for the solidification of hazardous wastes (5)(6). In general, they all utilize pozzolanic techniques and can be divided into two broad categories.

- **In-situ solidification** - wherein the wastes are solidified without being removed from the impoundment in which they are stored. Usually a backhoe is used with pneumatic injectors attached to the arm in order to introduce and blend the solidification agents into the waste.

- **External treatment** - wherein wastes are pumped out of, or otherwise excavated from, the storage area and are mixed with the solidification agents in trailer-mounted processing equipment and then placed in a temporary impoundment area or final repository site to cure and harden.

The first category is applicable to wastes contained in surface impoundment basins while the second category is applicable to these as well as wastes held in storage tanks awaiting processing and final disposal.

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CHAPTER 7.0

RESIDUE DISPOSAL TECHNOLOGIES

CHAPTER 7.0
RESIDUE DISPOSAL TECHNOLOGIES

The processing of hazardous waste results in residual materials that are not further processible by today's technologies. These materials can be either solids, liquids or gases and can be non-toxic or may exhibit varying degrees of toxicity and/or other hazardous properties thereby requiring disposal in a safe and secure manner.

GASEOUS RESIDUALS

There are several potential sources of gaseous emissions at a hazardous waste storage, treatment and destruction facility. The more significant ones, along with appropriate control technologies that can be used before discharging them to atmosphere are reviewed briefly under individual headings below.

Stack Emissions:

Stack emissions from thermal destruction processes will contain particulates as well as acid gases such as chloride (Cl), flourine (F), acids of sulphur (SO_x) and nitrogen (NO_x), and phosphoric anhydride (P_2O_5). Wet and dry scrubbing, electrostatic precipitation, and baghouse technologies commonly used to control these emissions are discussed in Chapter 4.0 of this document.

Tank Vents:

Tank vents on bulk liquid storage vessels, reaction vessels and from other vessels holding or processing hazardous liquids may contain entrained mist as well as organic and inorganic vapours, depending upon the nature of the vessel contents and the extent of any agitation or reaction occurring therein. Control technologies applicable here could include de-misting baffles, wet scrubbing devices using either acid or alkaline scrubbing media depend-

ing upon whether the fumes are alkaline or acidic respectively, and activated carbon adsorption beds or fume incinerators for organic vapours.

Building Vents:

Building vents generally will contain insignificant amounts of contaminants presuming that all vessels, material transfer points, etc., within the plant are adequately controlled. Nevertheless as an added precaution, the building vents could be directed through a High Efficiency Particulate Air (HEPA) filter and/or scrubbing device prior to discharge to the atmosphere.

Transfer Points:

Emissions associated with material transfer operations such as sampling, drum filling/emptying, conveyor discharges, hopper dumping, etc., may be of particulate or gaseous nature depending on the type of material being transferred. Permanently installed shrouds and ductwork can be used to enclose fixed transfer points such as conveyor and hopper discharges. Flexible "snorkel" or "elephant trunk" ductwork is available to draw emissions from sampling and drum filling/emptying operations. Control devices for particulate emissions could include baghouses or HEPA filters. For gaseous emissions wet scrubbers, activated carbon adsorption beds, or fume incinerators can be used as appropriate.

LIQUID RESIDUALS

Liquid emissions from a hazardous waste storage, treatment and destruction facility could include:

- Process effluents remaining after dewatering operations.
- Water from the wet quenching of thermal destruction system ash.
- Wet scrubber blowdown water.
- Contaminated water from plant equipment and vehicle washdown, spill cleanup, etc.

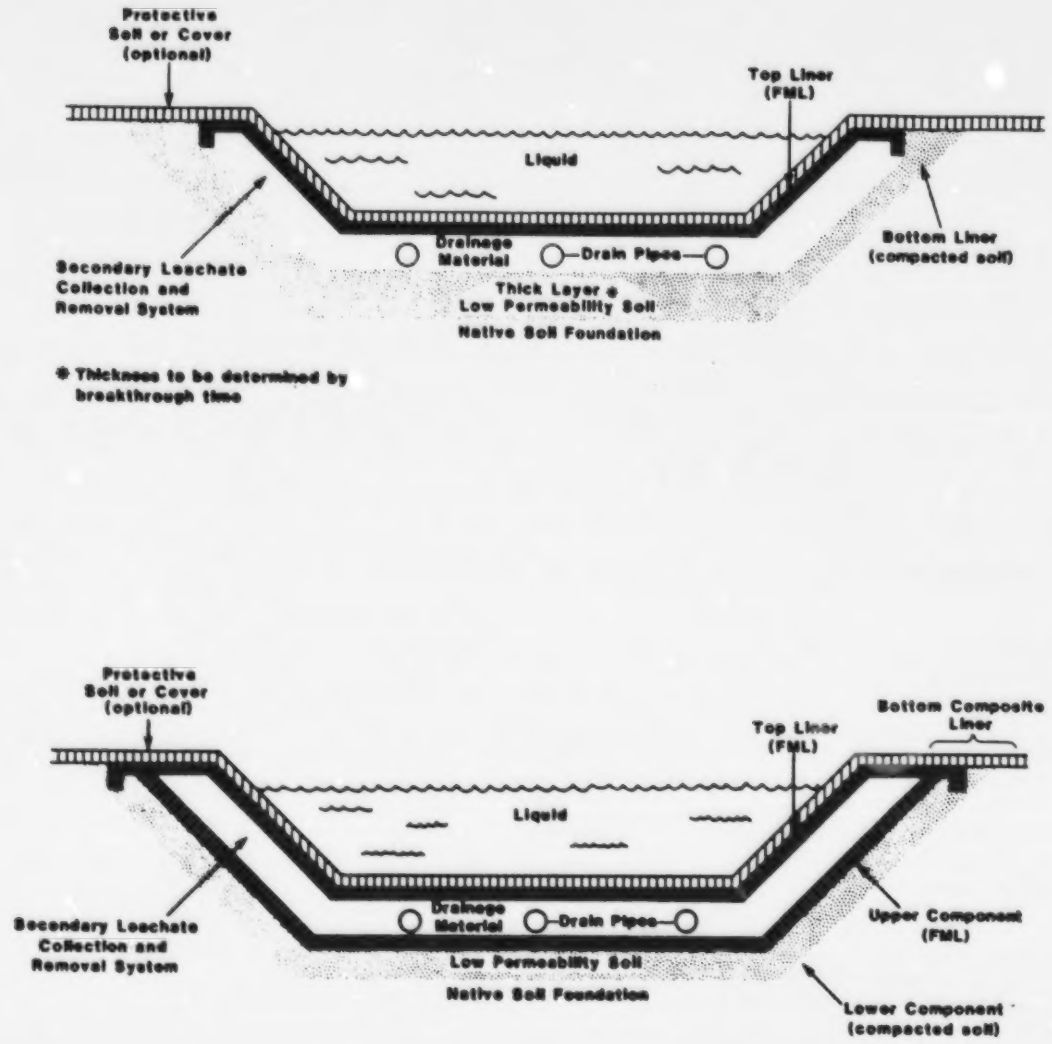


FIGURE 7-1:

Schematic Diagram of U.S. EPA's Double Liner
Evaporation Pond System
(After "The Hazardous Waste Consultant", 3, 4, 2-1, 1986)

- Contaminated storm runoff from "active" areas of the facility including roadways, tank farms, outdoor processing/materials handling areas, roof drains, etc.
- Presumably uncontaminated storm runoff from undeveloped areas of the site.

With the exception of the last one above, these effluents should be processed through a water treatment system prior to disposal. The components of the treatment system could consist of any of the unit operations described in Chapter 5.0. Alternately, some of the liquid residuals could be used as makeup water for pozzolanic immobilization processes described in Chapter 6.0.

Disposal techniques for liquid residuals generally fall into the three categories as described under separate headings below:

Evaporation Ponds:

Evaporation ponds can be used in regions where the net evaporation consistently exceeds the net precipitation by a significant margin (say at least 300 mm) on an annual basis. In Manitoba, this generally is the case in the southcentral and southwestern part of the Province.

Evaporation ponds are constructed with a high surface area to depth ratio to promote a high evaporation rate. Pond liners are used to protect against groundwater contamination. In the United States, the EPA has mandated under RCRA a double liner and leakage collection system as illustrated in Figure 7-1 (1).

Liquid wastes with significant amounts of toxic or odourous volatile organic or inorganic fractions should be excluded from evaporation ponds because of the risks that such components pose to ambient air quality in the vicinity of the pond.

Surface Water Discharges:

Uncontaminated surface runoff or process water treated to meet appropriate water quality limits may be discharged to a surface watercourse or waterbody for disposal. The surface runoff and/or treated effluent should be impounded prior to discharge to allow monitoring of water quality prior to release.

The advantages of this means of disposal include convenience, low cost, and ease of monitoring downstream impacts. The main disadvantage would be the public's perception that human health or the environment may be placed at undue risk due to the chance of direct contact with the effluent discharge. This concern can be addressed by ensuring that the water is treated to a high quality prior to impoundment, monitoring and release.

Subsurface Disposal Wells:

A recent report (2) on the current status of deepwell disposal of waste in Manitoba indicates that a number of waste disposal wells have operated in the Province. These include:

- Oil field brine injection in which brines withdrawn during commercial production of crude oil are re-injected into the Mississipian oil reservoir strata at depths ranging from 612 to 997 m below surface. This re-injection not only provides a means for disposing of the brine but also maintains pressure in the oil reservoir thereby improving oil production. This practice has occurred in the Southwestern part of the Province since the early 1950's when crude oil production in Manitoba began.

- Spent caustic generated by the Imperial Oil Refinery in Winnipeg was disposed by means of deepwell injection at a depth of 634 to 652.9 m in the Maples Field near Virden from 1969 to 1975.

- Spent cooling water from the air conditioning systems in theatres and restaurants and for cold-storage plants in Winnipeg is obtained and re-injected into the Paleozoic Carbonate Aquifer beneath the City of Winnipeg. This aquifer was used as a source of groundwater supply for the City prior to completion of the Greater Winnipeg Aquaduct in 1918.

- Waste brine from water softener regeneration at Manitoba Hydro's Dorsey D.C. Converter Station located 8 km northwest of Metropolitan Winnipeg is disposed by injection into the sandstone formation immediately overlying the Precambrian surface at a depth of about 228 m.

The same report (2) points out that any consideration of subsurface disposal should ensure that valuable subsurface resources such as hydrocarbons, natural gas, potash and other minerals, as well as usable freshwater and saltwater aquifers are not threatened. In addition, the basic requirements for a suitable disposal aquifer are defined in the report as:

- The disposal zone must have adequate porosity, permeability and volume to accept the necessary waste volume at the desired disposal rate. The porosity can be either natural or artificially induced.

- The waste must be "compatible" with both the formation fluid and the framework rock of the disposal zone or, alternatively, any waste interaction with the reservoir must be controllable.

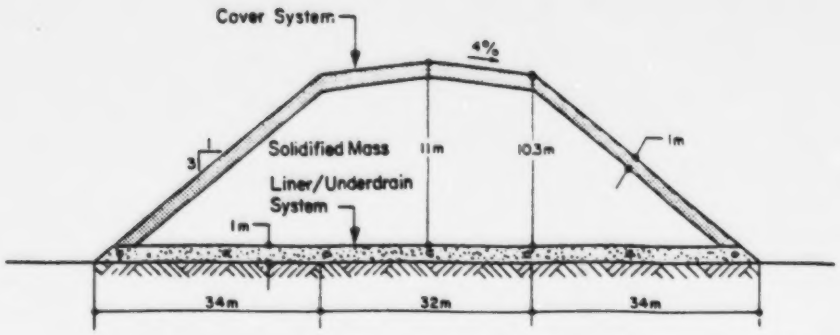
- The disposal reservoir, ideally, should be stratigraphically and hydrologically isolated from the biosphere. Factors determining the degree of isolation are, in estimated rank of importance:

  - impermeable cap rock and seat seal are adequate to confine waste to disposal zone;
  - stratigraphic isolation, i.e. reservoir strata do not extend to surface;
  - minimal regional flow of formation fluids in disposal zone;
  - structural integrity of reservoir beds, i.e. absence of fractures associated with local structural anomalies;
  - adequate depth from surface, and distance from outcrop - especially important if reservoir strata are not stratigraphically isolated;
  - lithofacies changes forming porosity and permeability barriers restricting intraformational fluid migration.

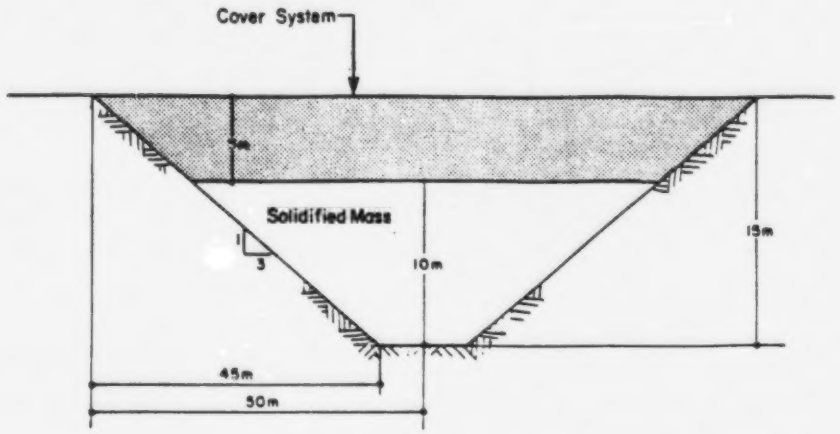
The report concludes that the sedimentary strata in the southwestern upland area of the Province are favourable for the subsurface disposal of liquid wastes. Dry holes drilled during the course of petroleum exploration or depleted oil-producing areas could be considered as suitable sites for waste disposal projects. Other areas of the Province are either not as favourable or are altogether unacceptable for deep well disposal when judged against the requirements listed above.

In Manitoba, the depth of burial of a proposed disposal aquifer is not necessarily an indicator of the most suitable stratum to inject the waste. For example in the southwestern part of Manitoba, the deepest aquifers are continuous to the outcrop belt generally dipping from east to west with potential for regional updip movement of groundwater. Some of the more

Above - Ground



Shallow Entombed



Conventional

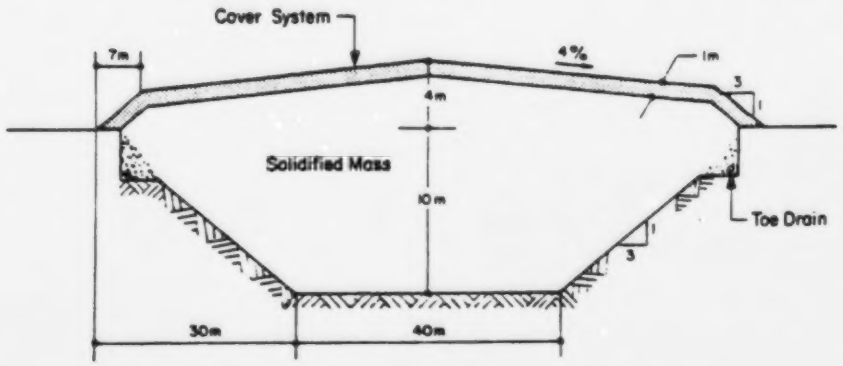


FIGURE 7-2:

Basic Repository Design Concepts
(After Ontario Waste Management Corporation, 1986)

shallow aquifers are stratigraphically isolated, or closed, by impermeable barriers and these are deemed to be more suited to deepwell disposal.

SOLID RESIDUALS

Common practice for the disposal of solid residuals is to select an appropriate site and to construct a secure repository in which to place these materials. The basic elements of secure repository design are reviewed under separate sub-headings below. In a few jurisdictions, containerized wastes are placed and sealed in deep subsurface repositories often constructed in worked-out mines. This technology is described under a final sub-heading.

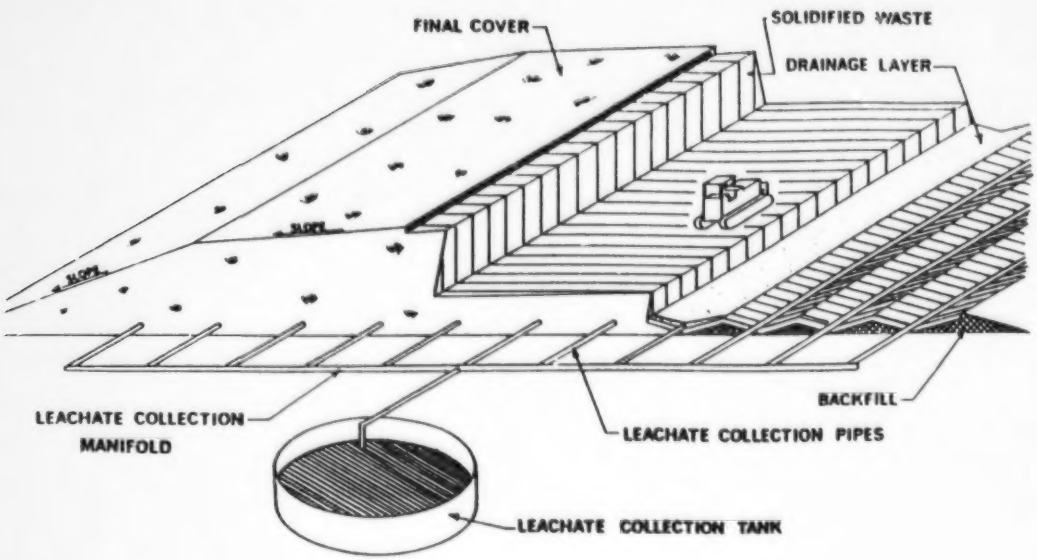
While in the past, liquids have been disposed in landfills, this practice is rapidly running out of favour because of potential groundwater contamination problems caused by leachate migration. Consequently it is becoming accepted practice to deposit only solid or solidified wastes into a secure repository containing hazardous wastes.

Design Concepts:

Figure 7-2 illustrates the three basic repository design concepts. They are described as (3):

- Above-ground - in which the waste materials are placed entirely above the original ground surface.
- Shallow entombed - in which the waste materials are placed below the base of the weathering zone. The finished top of the repository cover will be approximately at the original ground level.
- Conventional - in which the waste materials are placed both above and below the original ground surface, thereby balancing excavation volumes with repository cell cover and cap requirements.

Which concept is preferred will emerge from a consideration of various factors associated with the specific site chosen for the repository. Examples of such factors include topography and the desired finished grade eleva-



Schematic of an abovegrade landfill.

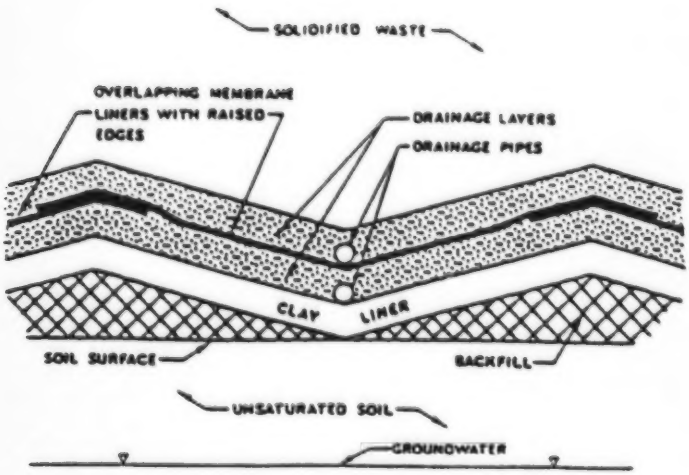


FIGURE 7-3:

Schematic of an Above-Ground Repository With Detail of Liner and Leachate Collection System (After Brown, K.W., and Anderson, D.C., 1983)

tions, soil stratigraphy and permeability, groundwater table elevation and gradient, climate, and availability of suitable borrow materials.

There is a growing debate over which design concept is preferred (4)(5) and currently, some momentum is building in favour of the above-ground concept. A schematic diagram of an above-ground repository with a detailed sketch of liner and leachate collection systems is illustrated in Figure 7-3. Proponents of the above-ground design concept (6)(7)(8) argue that its main advantages are:

- The repository is exposed on five of six sides and therefore it is easier to make liner and leachate collection system repairs.
- Leachate is readily removed by gravity drainage from beneath an above-ground repository. There is no need for pumping to remove leachate from beneath the repository.
- Because leachate is removed by gravity drainage, no appreciable hydraulic head is allowed to build up over the liner system. Thus the impermeability of the liner system is not continually stressed and, if a part of the liner system should rupture or otherwise fail, the amount of leachate lost would be less than if a "pool" of leachate were allowed to accumulate over the liner.
- Because the gravity drainage system does not allow "pools" of leachate to form in the bottom of the repository, a "corrugated" synthetic liner surface can be designed with overlapping liner seams as illustrated in detail of Figure 7-3 such that no reliance need be placed on the integrity of the liner seams to prevent leachate breakthrough.
- If a failure of the repository cover and cap system occurs, leachate due to infiltration of precipitation will be generated quite quickly. Monitoring of the gravity drainage system will facilitate rapid detection of the failure and therefore remedial measures can be undertaken at an early stage in the failure episode.
- Any gas generated by the decomposition of organic materials in the repository is less likely to migrate through subsurface pathways to adversely affect adjacent properties in an above-ground repository than in either a conventional or a shallow entombed repository.
- The contents of an above-ground repository are further separated from the groundwater table than in either a conventional or a shallow entombed repository. Thus the above-ground concept could provide better flexibility with respect to siting constraints than either of the other two concepts.

The main disadvantages of the above-ground concept are aesthetics and erosion potential. The former can be addressed by appropriate landscaping and buffer zone allowances. The latter can be addressed by appropriate design and specification of cover and cap materials, slopes and drainage channels, as well as provision of a protective vegetation mat.

The proponents of the shallow-entombed design concept (3) argue that if the solid waste residuals are placed below the weathered zone in a massive and thick low permeability continuous clay deposit, then the rate of migration of any leachate would be attenuated by the clay to a rate that is acceptable relative to the geologic timescale. Critics of the shallow-entombed concept claim that its main disadvantages are the relative inaccessibility of liner and leachate containment and withdrawal system should a mishap occur and remedial measures be required. In addition, an "active" leachate pumping system is required in perpetuity if leachate is produced.

The conventional repository design concept originates from the design of sanitary landfills for the disposal of municipal solid wastes wherein a trench is excavated, solid wastes are placed and compacted therein, and the previously excavated soils are used as daily cover material over the compacted wastes to form a discrete cell. The final grade elevation of the completed conventional design concept repository is determined by the materials balance between the originally excavated soils used for daily cell cover and final cap and the quantity of solid waste residuals placed in each cell. The conventional repository design has all of the disadvantages and none of the advantages of either the above-ground or shallow-entombed design concepts. Its chief advantage is that often an economic materials balance can be achieved between excavated soil and cell cover and final cap requirements.

Liner and Leachate Control Systems:

Liner and leachate control systems are used to ensure that contaminants contained within the hazardous waste repository do not migrate into the surrounding groundwater regime and cause harm to the environment (12).

The purpose of a liner is to impede or halt the migration of liquids (leachate or groundwater) into or out of the repository. Repository liners may be constructed either of natural or synthetic materials. The former includes clay and bentonite while the latter can include a variety of possibilities such as polyethylene, neoprene, butyl rubber, hypalon, and polyvinyl chloride. In recent years, high density polyethylene (HDPE) in 80 to 100 mil thicknesses has achieved popularity because of its strength and flexibility, resistance to tear and puncture, resistance to attack by many chemicals, pliability at low temperatures, and ease of welding seams together in the field.

The purpose of a leachate control system is to collect, for subsequent treatment, any contaminated leachate that might be generated from within the repository or from surface runoff and groundwater that may inadvertantly seep into the repository. Leachate normally is collected by a network of perforated pipes placed in a porous medium (say sand or graded gravel) at the bottom of the repository. The pipes conduct leachate to sumps from which it can be withdrawn for treatment. As an alternative to pipe collection systems on the sloping sides of a repository, synthetic drainage grids (geonets) and drainage mats (geotextiles) have been used.

There have been several concepts used for the design of liner and leachate control systems in hazardous waste secure repositories and no one concept is satisfactory for all circumstances. Much depends on the philosophical approach used in the development of the design concept for the repository. For example in the Province of Ontario, the Ontario Waste Management Corporation (3) has proposed a shallow entombed repository for its central treatment and disposal facility that relies entirely on a naturally-occurring massive clay deposit at the site to attenuate the migration of contaminants from the residuals deposited therein. On the other hand, the recently promulgated Special Waste Regulation in the Province of British Columbia requires dual liner systems (either synthetic flexible membranes or 0.5 m of clay) for repositories that will contain solid or solidified hazardous wastes. In a somewhat similar fashion, the U.S. EPA had previously mandated that hazardous waste repositories be lined with a double liner and two independent leachate collection and removal systems (9). At

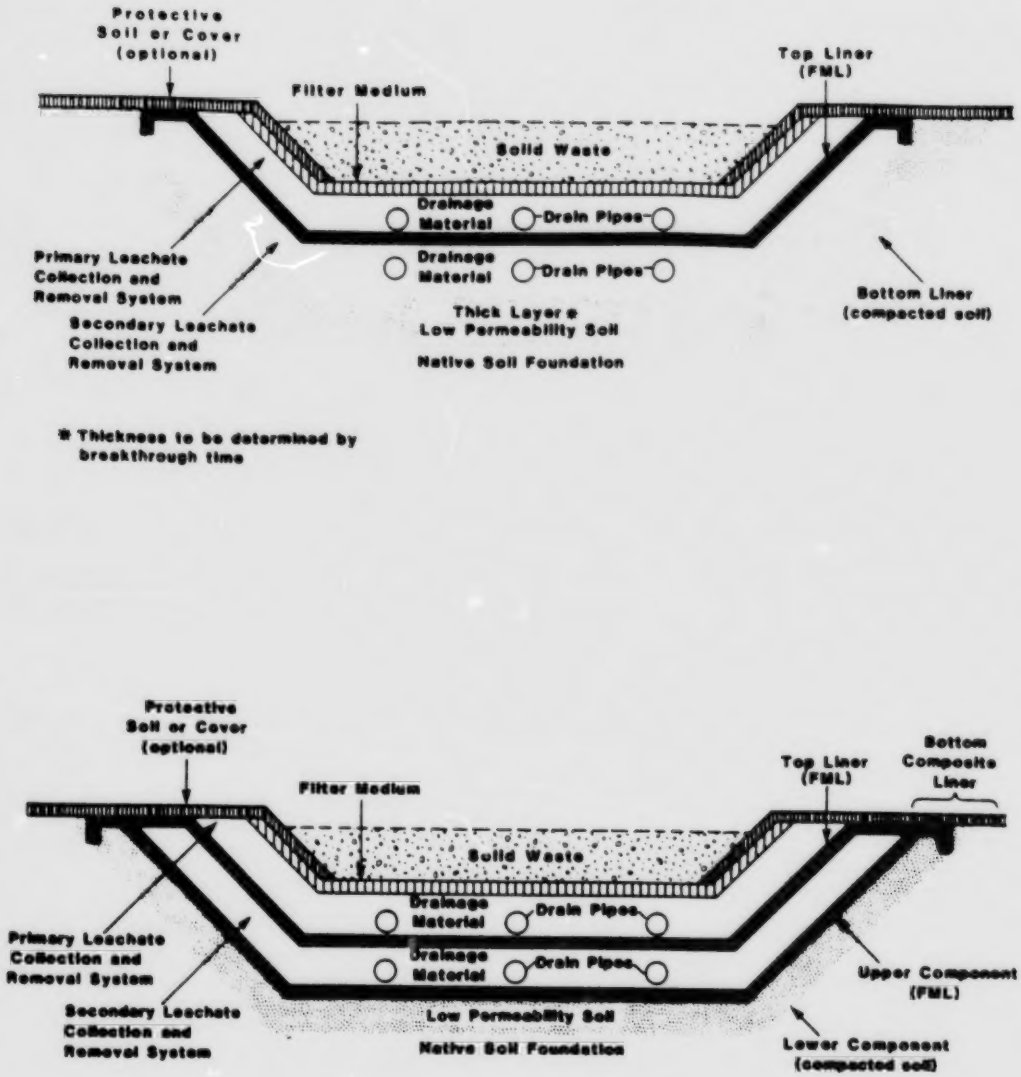


FIGURE 7-4:

Schematic Diagram of U.S. EPA's Double Liner
Landfill Systems
(After "The Hazardous Waste Consultant", 3, 4, 2-1, 1985)

least one of these must contain a flexible membrane liner. Sketches of the acceptable EPA liner configurations are illustrated in Figure 7-4. The repository at the Alberta Special Waste Treatment Centre in Swan Hills has been constructed more or less following the U.S. EPA concept with the exception that geonets are used rather than perforated collection pipes for leachate collection (10). Another repository constructed in Alberta has been described by Tsang (11). The liner and leachate control system incorporates two 100 mil polyethylene liners, three geonet/geotextile layers, and a 3 foot layer of compacted clay. A cross section of this liner and leachate control system is sketched in Figure 7-5.

Repository Cover:

The purpose of a final cover on a secure repository is to segregate the deposited hazardous materials from the environment, to minimize infiltration of surface runoff into the repository, and to protect against erosion and other undesirable weathering effects. The cover should have at least three components (12):

- A top layer of soil to encourage shallow rooted vegetation native to the area and to allow runoff without erosion.
- A drainage layer constructed of porous free-draining material that diverts any infiltration that may occur during sustained storm events.
- A barrier layer which prevents the infiltration of surface water into the repository itself.

The barrier layer should be integrated securely into the repository's liner system at the perimeter of the landfill. In addition, it should be below the depth of frost penetration to prevent damage that may occur during seasonal freeze/thaw cycles, and it also should be capable of withstanding any stresses due to subsidence that may occur in the wastes placed in the repository.

During the construction and operation of the repository, it has become accepted practice to provide a temporary cover to protect the working face and other exposed areas from precipitation.

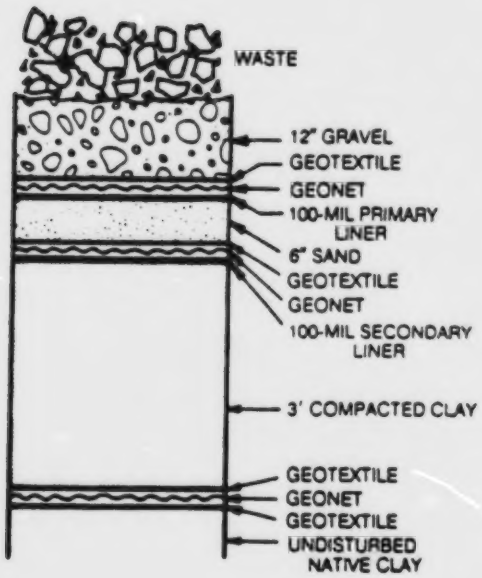


FIGURE 7-5:

Cross-Section Sketch of Liner and Leachate Control System (After Tsang, 1987)

Site Requirements:

The selection of an appropriate site is a very important consideration for a secure repository. From a technical view point, the significant geotechnical and hydrogeological conditions that generally are considered appropriate for hazardous waste repository site selection include:

- Uniform continuous clay deposits (low permeability materials)
- Remoteness from surface watercourses.
- Relatively flat topography.
- Low permeability rock underlying the site.
- Low natural hydraulic gradients.
- Geotechnical conditions conducive to installing monitoring wells economically such that leachate from the repository can be readily and quickly detected.
- Minimal susceptability to weathering of soil deposits.
- Geotechnical conditions favourable to construction of roadways, embankments, repository cells, and so on.

Seasonal Constraints:

Some form of shelter or enclosure should be provided to prevent precipitation from falling on and collecting in the open working areas of the repository. It is possible that the final placement of wastes in a secure repository in Manitoba will be constrained during the winter months. Should the placement of wastes during extremely cold winter periods become difficult or impossible, then an enclosed secure interim storage area should be provided for temporary storage of solid residuals until access to the secure repository can be gained during more moderate weather conditions.

Deep Subsurface Disposal:

Two types of deep subsurface disposal repositories have been suggested as having potential for the disposal of solid residues:

- Deposition of wastes in mined-out salt domes or other deep reused mines.
- Deposition of wastes deep in the plutonic rock of the Canadian Shield in caverns constructed specifically for this purpose.

The former is practiced in West Germany and is noted in the report by the Canadian Fact-Finding Mission on Hazardous Waste Management in Europe (13). Palletized containers (drums) of hazardous waste are hoisted down the shaft of the operating Kali und Salz salt mine and stored in mined-out areas of the salt deposit. When a sufficient quantity of waste is stored in one area, that area is sealed off with concrete and grout to secure the wastes. It is conceivable that the wastes could be retrieved at some future time but the feasibility of safely accomplishing this objective after a lengthy storage period is questionable. Confidence in the security of this residue disposal method lies in the fact that the minerals (say salt) were securely in place over a long period in the geologic time scale and that, as long as suitable precautions are taken to avoid flooding of the mine or other mishap that would result in groundwater migration through the mine, there is no reason to believe that the residues deposited therein should pose a threat to the environment. In Manitoba, there might be potential to apply this method of solid residue disposal in the mined-out salt deposits near Neepawa. However concerns over the long term integrity of this technique remain, particularly in view of the serious flooding problems recently experienced at two potash mines in eastern Saskatchewan near the Manitoba border.

The latter deep subsurface disposal method, applicable to high level nuclear wastes, is the subject of an extensive research program by Atomic Energy of Canada Limited (14)(15). Concerns related to the development of a non-nuclear hazardous waste management system would be the cost of developing and monitoring a deep mine in the hard rock of the Canadian Shield, as well

as the long term security of the wastes to be buried in this fashion given the movement of groundwater through the fractures of the Precambrian rock.

DISPOSAL COSTS

A recent U.S. EPA survey of selected operating firms in the commercial hazardous waste management industry reported in Reference (16) indicates the following prices (expressed in 1987 Canadian dollars) for placement of solid residues in a secure repository and also for deepwell disposal of liquid residuals.

Waste Management Technology	Type of Waste	Price (Converted to 1987 $Cdn)
Secure Repository	Bulk Solids	$126 to $216 per tonne
Deepwell Injection	Aqueous Organics and Oily Wastewaters	$ 31 to $172 per tonne
Deepwell Injection	Other Toxic Liquids	$ 52 to $217 per tonne

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CHAPTER 8.0

APPLICATION TO MANITOBA

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APPLICATION TO MANITOBA

PREAMBLE

This Chapter reviews the technologies discussed in previous Chapters in light of the current understanding of the hazardous waste quantities generated in the Province of Manitoba. With the aid of criteria formulated specifically to reflect the Manitoba situation, technologies that are potentially applicable to the management of Manitoba's hazardous waste are identified.

The analysis in this Chapter is based upon the hazardous waste quantities specified in the 1985 report prepared by Manitoba Environment and Workplace Safety and Health (1). That report includes the following estimates:

- A total of 20,000 tonnes per year of hazardous waste potentially available for off-site treatment and disposal are generated in the Province.
- Of this quantity, approximately 15,000 tonnes per year are inorganic wastes and are generally classified as "corrosives". About 8,000 tonnes per year of these are generated in the Winnipeg and southeastern Manitoba area, 5,000 tonnes per year in western Manitoba, and 2,000 tonnes per year in northern Manitoba.
- The remaining 5,000 tonnes per year of the total hazardous waste stream are organic wastes and are generated mostly in the greater Winnipeg area. Within this category, there is roughly a 80 percent - 20 percent split between liquid organic and solid organic wastes.

The Manitoba Hazardous Waste Management Corporation has cautioned that these inventory figures are approximate only and at best are within plus or minus 50 percent. Furthermore the 80 percent - 20 percent split between liquid and solid organics maybe erroneous in that many of the "liquids" may include sludges or considerable amounts of solids in suspension. Nevertheless, these data are believed to be the best hazardous waste inventory estimates for the Province of Manitoba that are available at this time. The Corporation recently has commissioned a study that is yet to be completed that will update this information. It is recommended that when the new information is

available, the analysis presented in this Chapter be updated if the new inventory figures deviate substantially from those presented in the 1985 report.

The analysis in this Chapter dwells for the most part on the thermal destruction, physical-chemical, immobilization and residue disposal technologies reviewed in Chapters 4.0 through 7.0 in this report. With regard to the waste storage, transfer and transportation technologies discussed in Chapters 2.0 and 3.0, suffice to say that all of these technologies are potentially applicable to the management of hazardous waste in Manitoba.

CRITERIA

Ten criteria have been developed for application to the various technologies in order to determine which ones are most suited to Manitoba. The criteria are as follows:

(1) Resource Recovery Opportunities:

- Does the technology, either by itself or in combination with other technologies, provide opportunities for materials and/or energy recovery?

(2) Scale Re: Manitoba Situation:

- Is the scale (size) of the technology appropriate to the processing of the quantities of wastes that are thought to be generated in Manitoba?

(3) Flexibility Re: Waste Types:

- Is the technology applicable to the processing of a wide variety of waste types (acids, alkalis, non-halogenated and halogenated hydrocarbons, etc.)?
- Can it handle these wastes in a variety of forms (liquids, slurries, sludges, pastes, bulk solids, drums, etc.)?

(4) State of Technology Development:

- Has the technology successfully been demonstrated at the bench or pilot scale level?
- Has the technology successfully been applied on a full-scale basis for the processing of hazardous wastes?
- Has the technology progressed to the point of commercial acceptance?

(5) **Technical Performance:**

- Are the "bugs" out of the system?
- Has the technology operated successfully in climatic conditions similar to Manitoba's?

(6) **Risks Re: Residuals and Emissions:**

- Are there significant concerns about the hazards posed by the liquid, gaseous or solid by-products of the process?
- Are there practical and realistic methods available to monitor the potential emissions and impacts of the facility?

(7) **Regulatory Acceptance:**

- Have regulatory authorities in other jurisdictions given approval to the process for hazardous waste treatment applications?
- Does the process achieve satisfactory levels of hazard reduction based on prevailing or anticipated Manitoba standards?

(8) **Opportunity for Mobility and/or Transportability:**

- Are commercial mobile and/or transportable processing units available?
- If not, is there potential for constructing mobile and/or transportable units?
- "Mobility" implies capability to be transported, set up, and operational on a site within two weeks.
- "Transportability" implies that the same capability takes longer than two weeks.

(9) **Infrastructure Requirements:**

- What amount of infrastructure is required to support installation of the technology on a specific site?

Small:	A relatively small amount of infrastructure support is required for the technology.
Moderate:	A moderate amount is required.
Large:	A relatively large amount is required.

(10) **Costs:**

- What are the unit processing costs?

Low	< $250 per tonne
Medium	$250 to $750 per tonne
High	> $750 per tonne

- The term "costs" represents the capital replacement plus operating and maintenance costs (expressed in 1987 Canadian dollars) associated with the specific technology under consideration and does not include waste collection and transportation costs. Neither does it include solid residue disposal costs unless the technology is specifically intended for residue disposal such as pozzolanic immobilization techniques or the placement of solid residues in a secure repository. Similarly the costs for placement of solid residues in a secure repository do not allow for any processing measures used to render the wastes solid and/or non-leachable prior to placement. And finally, the costs do not include any credit for the recovery and sale of a re-useable component from a waste stream.

- The information used to determine unit processing costs was drawn from the following references: (2)(3)(4)(5).

APPLICATION OF CRITERIA

Tables 8-1, 8-2, 8-3, 8-4, and 8-5 located at the end of this Chapter of the report present the results of applying the ten criteria to the thermal destruction technologies, physical unit operations, chemical unit operations, immobilization, and residue disposal technologies respectively that were described in Chapters 4.0 through 7.0 of this report. Additional rows and an extra column are included on each table to allow the reader to add other criteria or technolgies as desired.

The exercise of applying the criteria to the various technologies was performed first by Reid Crowther and then, in order to refine the selection of preferred technologies, applied a second time in a joint workshop session with participants from both Reid Crowther and the Manitoba Hazardous Waste Management Corporation. The entries in Tables 8-1 through 8-5 reflect the general consensus reached during the workshop session.

In applying the criteria, it was assumed that at some future date, a central hazardous waste management facility will be built in the Province of Manitoba.

PREFERRED TECHNOLOGIES

After consideration of all comments in the tables, the following conclusions are made regarding the applicability of the various technologies reviewed in

this report for inclusion in a central hazardous waste management facility in Manitoba:

- **Thermal Destruction Technologies (Table 8-1):**

  - Considering economics, industrial co-disposal using a cement kiln appears to be the most appropriate thermal destruction option for Manitoba's organic hazardous wastes. Much of the capital facilities and infrastructure are already in place; the major expense would be the construction of a waste receiving and storage facility, as well as the necessary kiln feed preparation facilities. A large fraction of the 5,000 tonnes per year of organic hazardous wastes generated in Manitoba likely could be destroyed using this technology. The remainder could be shipped to suitable out-of-province treatment and disposal facilities as required.

  - If the above option is not available, then shipping Manitoba's organic hazardous wastes to out-of-province thermal destruction facilties would be most appropriate. This would take advantage of the lower unit processing costs often associated with economics of scale and the competitive spot market availability of incineration capacity that sometimes occurs.

  - If the above two options are not available, then a mobile/transportable rotary kiln system is deemed to be appropriate technology because it would be able to handle the wide variety of waste types and forms commonly encountered in hazardous waste management. Wastes could be stockpiled at a central processing facility and the mobile/transportable unit could be brought in on a periodic basis to deal with the accumulated wastes. In order to reduce the unit processing costs for this option, it would be desirable to import wastes from out-of-province as additional feedstock for the kiln system.

  - Assuming the validity of current hazardous waste inventory information, the stationary rotary kiln, which is a commonly employed technology in other jurisdictions for hazardous waste destruction, is rejected primarily because of the relatively small annual quantity of organic hazardous wastes generated in Manitoba. It would not be cost-effective as long as other options are available. It is possible, however, that the rocking kiln modification of the rotary kiln concept could be applicable to Manitoba's circumstances.

  - Liquid injection, fixed hearth and fluidized bed incineration are not appropriate for dealing with Manitoba's organic hazardous wastes because they cannot handle the variety of waste types and forms commonly generated. Furthermore, it is reasonable to expect that the total quantity of relatively easy to process waste types and forms that these incinerators are capable of handling will diminish in the future as waste reduction, recovery, recyle and reuse practices become more widespread.

- The two infrared technologies are rejected because they are suited primarily to dealing with contaminated site clean-ups. However, this decision is not intended to exclude them from consideration if a mobile/transportable incineration unit is required for remedial work at a specific site.

- The plasma arc, the Joule-melting furnace and the electric pyrolyzer are identified as emerging technologies worth reconsideration at the appropriate intervals during the Corporation's incremental system development program. Likewise the Taciuk Processor is worth reconsidering for treating contaminated soils at a remedial work site.

- Wet oxidation is rejected primarily because of its applicability only to semi-dilute waste, and also because of its relatively low destruction and removal efficiency which would necessitate an additional polishing treatment step. The molten salt and supercritical water technologies are rejected primarily because of their immature stage of technology development.

- **Physical Unit Operations (Table 8-2):**

  - In general, all of the physical unit operations reviewed in Chapter 5.0 are potentially applicable to the management of Manitoba's hazardous wastes and could be incorporated into a physical/chemical treatment process as part of a provincial hazardous waste management system.

  - A few of the technologies, namely distillation and solvent extraction, and possibly evaporation, ion exchange and membrance separation, are applicable to site-specific and/or waste-specific circumstances for possible resource recovery applications. These could be installed on an individual waste generator's site or at some central location with convenient access for a number of waste generators.

- **Chemical Unit Operations (Table 8-3):**

  - In general, all of the chemical unit operations reviewed in Chapter 5.0 are potentially applicable to the management of Manitoba's hazardous wastes and could be incorporated into a physical/chemical treatment process as part of a provincial hazardous waste management system.

- **Immobilization Technologies (Table 8-4):**

  - Of the four immobilization technologies, only the pozzolanic techniques are believed to be applicable to the management of hazardous wastes in Manitoba and could be incorporated into a provincial hazardous waste management system.

  - The binding and encapsulation technologies generally are not applicable but might be justified for dealing with specific waste streams of relatively small volume.

- The Battelle in-situ vitrification process is worth watching as an emerging technology for possible application to remedial site clean-up projects.

- **Residue Disposal Technologies (Table 8-5):**

  - For disposal of liquid residues, all of the technologies reviewed in this report (evaporation ponds, surface water discharges, and subsurface disposal wells) are potentially applicable in Manitoba and could be employed at provincial hazardous waste management facilities. However, certain siting considerations apply for evaporation ponds (restricted to the more arid southern parts of the province) and subsurface disposal wells (applicable only in the southwestern part of the province).

  - For the disposal of solid residues, as yet there is no "ideal" or "perfect" solution, however, technology for secure repositories is evolving and consideration should be given to the above-ground repository concept because of the advantages it offers in terms of ease of monitoring and accessibility to rectify any problems should they occur.

THERMAL DESTRUCTION TECHNOLOGIES

TABLE 8-1

CRITERIA / TECHNOLOGIES	(1) RESOURCE RECOVERY OPPORTUNITIES	(2) SCALE RE- MANITOBA SITUATION	(3) FLEXIBILITY RE- WASTE TYPES/FORMS	(4) STATE OF TECHNOLOGY DEVELOPMENT	(5) TECHNICAL & ENVIRONMENTAL PERFORMANCE	(6) RISKS RE- RESIDUALS & EMISSIONS	(7) REGULATORY ACCEPTANCE ELSEWHERE	(8) OPPORTUNITY FOR MOBILITY & / OR TRANSPORTABILITY	(9) INFRASTRUCTURE REQUIREMENTS	(10) COSTS	
LIQUID INJECTION	NO	OK	BULK LIQUIDS ONLY	COMMERCIAL	OK	OK	OK	MOBILE	LARGE	MEDIUM TO HIGH	
ROTARY KILN	NO	NOT ENOUGH WASTES TO BE COST-EFFICIENT	LARGE KILN ACCEPTS ALL WASTES/FORMS	COMMERCIAL	OK BUT SOME CONCERN RE- WINTER OPERATION OF NON-STATIONARY UNITS	OK	OK	SMALL ONES-MOBILE LARGE ONES-TRANS-PORTABLE VERY LARGE ONES STATIONARY	LARGE	MEDIUM TO HIGH	
CONTROLLED AIR	NO	OK	BULK LIQUIDS AND SOLIDS; PACKAGED SOLIDS	COMMERCIAL	OK	OK	OK	STATIONARY BUT COULD BE MOVED	LARGE	MEDIUM TO HIGH	
FLUIDIZED BED (BUBBLING BED)	NO	OK	BULK LIQUIDS AND SIZE-REDUCED NON-FUSIBLE SOLIDS	COMMERCIAL	OK BUT CONCERN RE- WINTER OPER-ATION OF NON-STATIONARY UNITS	OK	OK	STATIONARY AND TRANSPORTABLE	LARGE	MEDIUM TO HIGH	
FLUIDIZED BED (CIRCULATING BED)	NO	OK	BULK LIQUIDS AND SIZE-REDUCED NON-FUSIBLE SOLIDS	FULL-SCALE DEMO/ COMMERCIAL	OK BUT SOME CONCERN RE- WINTER OPERATION OF NON-STATIONARY UNITS	OK	OK	STATIONARY AND TRANSPORTABLE	LARGE	MEDIUM TO HIGH	
PLASMA ARC	POSSIBLE FUEL-GAS VALUE IN EXHAUST GASES	OK	BULK LIQUIDS AND SLURRIES	FULL-SCALE DEMO/ COMMERCIAL	OK	TO BE DEMONSTRATED	NOT YET	STATIONARY AND MOBILE	LARGE	MEDIUM TO HIGH	
WET OXIDATION	NO	OK	BULK LIQUIDS, SLURRIES, AND SLUDGES; SEMI-DILUTE	COMMERCIAL	ONLY 80 TO 99% DESTRUCTION AND REMOVAL EFFICIENCY	EFFLUENT NEEDS FURTHER TREATMENT	NOT FOR HAZ. WASTES	STATIONARY AND MOBILE	LARGE	MEDIUM	
INFRARED (A.E.R.)	NO	OK FOR POSSIBLE SHORT TERM SITE CLEANUPS	BULK CONTAM-INATED SOILS AND OTHER SOLIDS	FULL-SCALE DEMO/ COMMERCIAL	OK BUT SOME CONCERN RE- WINTER OPERATION OF NON-STATIONARY UNITS	OK	OK	TRANSPORTABLE	LARGE	MEDIUM TO HIGH	
INFRARED (SHIRCO)	NO	OK FOR POSSIBLE SHORT TERM SITE CLEANUPS	BULK CONTAM-INATED SOILS AND OTHER SOLIDS	COMMERCIAL	OK BUT SOME CONCERN RE- WINTER OPERATION OF NON-STATIONARY UNITS	OK	OK	TRANSPORTABLE	LARGE	MEDIUM TO HIGH	
MOLTEN SALT	NO	UNCERTAIN	LIQUIDS	EXPERIMENTAL	UNCERTAIN	UNCERTAIN	NO	NOT YET	LARGE	HIGH	
SUPERCRITICAL WATER	NO	UNCERTAIN	LIQUIDS	EXPERIMENTAL	UNCERTAIN	UNCERTAIN	NO	NOT YET	LARGE	HIGH	
JOULE-MELTING FURNACE	NO	OK	BULK LIQUIDS AND SOLIDS; PACKAGED SOLIDS	FULL-SCALE DEMO/ COMMERCIAL	OK BUT SOME CONCERN RE- WINTER OPERATION OF NON-STATIONARY UNITS	OK	NOT YET	STATIONARY AND MOBILE	LARGE	MEDIUM TO HIGH	
ELECTRIC PYROLYZER	NO	OK	BULK CONTAM-INATED SOILS AND OTHER SOLIDS	FULL-SCALE DEMO	POSSIBLY OK BUT ADDITIONAL TESTING IN PROGRESS	UNCERTAIN	NOT YET	MOBILE	LARGE	NOT KNOWN - LIKELY MEDIUM TO HIGH	
TACIUK PROCESSOR	NO	OK	BULK CONTAM-INATED SOILS AND OTHER SOLIDS	PILOT / FULL-SCALE DEMO	UNCERTAIN	UNCERTAIN	NO	COULD BE MOBILE	LARGE	NOT KNOWN - LIKELY MEDIUM TO HIGH	
INDUSTRIAL CO-DISPOSAL	AS FUEL SUPPLEMENT	OK	LIQUIDS AND SLURRIES	COMMERCIAL	OK	OK PROVIDING ADEQUATE EMISSION CONTROLS	OK	STATIONARY	MODERATE	LOW TO MEDIUM	

PHYSICAL UNIT OPERATIONS

TABLE 8-2

CRITERIA / TECHNOLOGIES	(1) RESOURCE RECOVERY OPPORTUNITIES	(2) SCALE RE- MANITOBA SITUATION	(3) FLEXIBILITY RE- WASTE TYPES/FORMS	(4) STATE OF TECHNOLOGY DEVELOPMENT	(5) TECHNICAL & ENVIRONMENTAL PERFORMANCE	(6) RISKS RE- RESIDUALS & EMISSIONS	(7) REGULATORY ACCEPTANCE ELSEWHERE	(8) OPPORTUNITY FOR MOBILITY & / OR TRANSPORTABILITY	(9) INFRASTRUCTURE REQUIREMENTS	(10) COSTS	
STRIPPING	NO	OK	RELATIVELY DILUTE CYANIDES, SULPHIDES &VOLATILE HYDROCARBONS	COMMERCIAL	OK	TREAT OFF-GASES; POLISH BOTTOMS	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	LOW TO MEDIUM	
EVAPORATION	GENERALLY NONE EXCEPT FOR DRAG-OUT CONCENTRATING AND RECYCLING	OK	SLURRIES &SLUDGES	COMMERCIAL	OK	TREAT- OFF-GASES	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	MEDUIM TO HIGH	
DISTILLATION	SOLVENT RECOVERY	OK	HYDROCARBONS	COMMERCIAL	OK	TREAT BOTTOMS	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	MEDUIM TO HIGH	
SOLVENT EXTRACTION	SOLVENT RECOVERY	OK	HYDROCARBONS	COMMERCIAL	OK	TREAT SOLVENT; MAYBE TREAT RAFFINATE	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	MEDIUM TO HIGH	
FILTRATION	GENERALLY NONE	OK	SLURRIES &SLUDGES	COMMERCIAL	OK	TREAT BACKWASH; MAYBE TREAT FILTRATE	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	LOW	
PHASE SEPARATION	GENERALLY NONE	OK	SLURRIES AND 2-PHASE IMMISCIBLES	COMMERCIAL	OK	TREAT DECANT AND UNDERFLOW	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	LOW	
ACTIVATED C ADSORPTION	GENERALLY NONE	OK	RELATIVELY DILUTE HYDROCARBONS AND SOME METALS	COMMERCIAL	OK	TREAT/REGENER SPENT CARBON, TREAT REGENER	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	MEDIUM	
ION EXCHANGE	METALS RECOVERY AND DRAG-OUT CONCENTRATION AND RECYCLING	OK	DILUTE DISSOLVED INORGANICS	COMMERCIAL	OK	TREAT REGENERANT	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	MEDIUM	
MEMBRANE SEPARATION	GENERALLY NONE EXCEPT FOR DRAG-OUT CONCENTRATING AND RECYCLING	OK	DILUTE SOLUTIONS	COMMERCIAL	OK	TREAT BLOW-BY	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	MEDIUM	

CHEMICAL UNIT OPERATIONS

TABLE 8-3

CRITERIA / TECHNOLOGIES	(1) RESOURCE RECOVERY OPPORTUNITIES	(2) SCALE RE- MANITOBA SITUATION	(3) FLEXIBILITY RE- WASTE TYPES/FORMS	(4) STATE OF TECHNOLOGY DEVELOPMENT	(5) TECHNICAL & ENVIRONMENTAL PERFORMANCE	(6) RISKS RE- RESIDUALS & EMISSIONS	(7) REGULATORY ACCEPTANCE ELSEWHERE	(8) OPPORTUNITY FOR MOBILITY & / OR TRANSPORTABILITY	(9) INFRASTRUCTURE REQUIREMENTS	(10) COSTS	
REDOX	LIKELY NONE	OK	LIQUIDS, SLURRIES AND SLUDGES	COMMERCIAL	OK	FURTHER TREATMENT LIKELY REQUIRED	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	MEDIUM TO HIGH	
NEUTRALIZATION	LIKELY NONE	OK	LIQUIDS, SLURRIES AND SLUDGES	COMMERCIAL	OK	FURTHER TREATMENT LIKELY REQUIRED	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	LOW	
PRECIPITATION	LIKELY NONE	OK	LIQUIDS, SLURRIES AND SLUDGES	COMMERCIAL	OK	FURTHER TREATMENT LIKELY REQUIRED	OK	STATIONARY AND MOBILE	SMALL TO MODERATE	LOW	
DECHLORINATION	RE-USE OIL ?	OK	LIQUID PCB'S UPTO 5000 PPM	COMMERCIAL	OK	OK	OK	GENERALLY MOBILE	SMALL TO MODERATE	MEDIUM TO HIGH	

IMMOBILIZATION TECHNOLOGIES

TABLE 8-4

CRITERIA / TECHNOLOGIES	(1) RESOURCE RECOVERY OPPORTUNITIES	(2) SCALE RE- MANITOBA SITUATION	(3) FLEXIBILITY RE- WASTE TYPES/FORMS	(4) STATE OF TECHNOLOGY DEVELOPMENT	(5) TECHNICAL & ENVIRONMENTAL PERFORMANCE	(6) RISKS RE- RESIDUALS & EMISSIONS	(7) REGULATORY ACCEPTANCE ELSEWHERE	(8) OPPORTUNITY FOR MOBILITY & / OR TRANSPORTABILITY	(9) INFRASTRUCTURE REQUIREMENTS	(10) COSTS	
POZZOLANIC TECHNIQUES	NO BUT MIGHT BE USABLE AS AN AGGREGATE OR STRUCTURAL MATERIAL	OK	INORGANIC LIQUIDS, SLURRIES & SLUDGES WITH < 20% ORGANICS & LOW SOLUBLES	COMMERCIAL	OK	OK	OK	STATIONARY AND MOBILE	SMALL	LOW TO MEDIUM	
BINDING TECHNIQUES	NO	OK	SLURRIES, SLUDGES, PASTES ANS SOLIDS W/O SOLVENTS	COMMERCIAL BUT NOT WIDELY APPLIED	GENERALLY OK	OK BUT POSSIBLE SWELLING IF IT HYDRATES	UNCERTAIN	UNCERTAIN	MODERATE	MEDIUM TO HIGH	
ENCAPSULATION TECHNIQUES	NO	OK	SLUDGES, PASTES AND SOLIDS (GENERALLY NON-AQUEOUS)	COMMERCIAL BUT NOT WIDELY APPLIED	QUESTIONS RE LONG TERM STABILITY	UNCERTAIN	UNCERTAIN	UNCERTAIN	MODERATE	MEDIUM TO HIGH	
VITRIFICATION TECHNIQUES	NO	OK	GRANULAR SOLIDS AND IN SITU CONTAMINATED SOILS	FULL SCALE DEMO	UNCERTAIN	UNCERTAIN	UNCERTAIN	STATIONARY, MOBILE AND IN SITU FACILITIES	MODERATE	MEDIUM TO HIGH	

RESIDUE DISPOSAL TECHNOLOGIES

TABLE 8-5

CRITERIA / TECHNOLOGIES	(1) RESOURCE RECOVERY OPPORTUNITIES	(2) SCALE RE- MANITOBA SITUATION	(3) FLEXIBILITY RE- WASTE TYPES/FORMS	(4) STATE OF TECHNOLOGY DEVELOPMENT	(5) TECHNICAL & ENVIRONMENTAL PERFORMANCE	(6) RISKS RE- RESIDUALS & EMISSIONS	(7) REGULATORY ACCEPTANCE ELSEWHERE	(8) OPPORTUNITY FOR MOBILITY & / OR TRANSPORTABILITY	(9) INFRASTRUCTURE REQUIREMENTS	(10) COSTS	
EVAPORATION POND	NO	OK	TREATED AQUEOUS WASTES	COMMERCIAL	OK FOR SOUTHERN PART OF MANITOBA	OK PROVIDING PRE-TREATMENT FOR REMOVAL OF VOLATILES	OK	CRITERION NOT APPLICABLE	SMALL	LOW	
SURFACE WATER DISCHARGE	NO	OK	TREATED AQUEOUS WASTES	COMMERCIAL	OK	OK PROVIDING ADEQUATE TREATMENT PRIOR TO DISCHARGE	OK	CRITERION NOT APPLICABLE	SMALL	MEDIUM	
SUBSURFACE DISPOSAL WELL	NO	POSSIBLY OK	PRE-TREATED AQUEOUS WASTES AND BRINES	COMMERCIAL	OK FOR SOUTH-WESTERN PART OF MANITOBA	OK PROVIDED SUITABLE AQUIFER IS SELECTED	OFTEN OK BUT FORBIDDEN IN SOME JURISTICTIONS	CRITERION NOT APPLICABLE	SMALL TO MODERATE	LOW	
SECURE REPOSITORY	POSSIBLY BUT DOUBTFUL	OK	GENERALLY SUITED TO BULK OR CONTAIN-ERIZED SOLIDS	COMMERCIAL WITH CONTINUING TECHNOLOGY	OK BUT SEE (6) ADJASCENT ---->	SOME CONCERN RE- LONG TERM INTEGRITY OF SECURITY MEASURES	OK	CRITERION NOT APPLICABLE	MODERATE	LOW	
DEEP SUBSURFACE REPOSITORY	POSSIBLY BUT QUESTIONABLE	QUESTIONABLE IF SUFFICIENT CAPACITY CAN BE MADE AVAILABLE	GENERALLY SUITED TO CONTAINERIZED SOLIDS	COMMERCIAL FACILITY IN EUROPE	OK BUT SEE (6) ADJASCENT ---->	SOME CONCERN RE- POTENTIAL FOR GROUND-WATER TO CAUSE LEACHATE MIGRATION	OK	CRITERION NOT APPLICABLE	MODERATE	MODERATE	

RDT-1

REFERENCES FOR CHAPTER 8.0
APPLICATION TO MANITOBA

(1) YEE, E., KUCERA, E., and KELEHER, J.J., "Hazardous Waste Management in Manitoba", Report prepared for Manitoba Environment and Workplace Safety and Health, July, 1988.

(2) MACKIE, J.A. and NIESEN, K., "Hazardous Waste Management: The Alternatives", Chemical Engineering, p. 51, August 6, 1984.

(3) ANONYMOUS, "Chemical Waste Management Analyzes Demand and Pricing for Destruction Services", The Hazardous Waste Consultant, 6, No. 2, 1-5, March-April, 1988.

(4) ANONYMOUS, "Hazardous Waste Capacity Estimates Reveal Some Surprises", The Hazardous Waste Consultant, 6, No. 4, 1-1, July-August, 1988.

(5) CONNER, J.R., "Fixation and Solidification of Wastes", Chemical Engineering, P. 79, November 10, 1988.

APPENDIX A

MANUFACTURERS AND SUPPLIERS

APPENDIX A
MANUFACTURERS AND SUPPLIERS

Corporate names, addresses, personnel contacts and telephone numbers are listed on the following pages for the various types of hazardous waste treatment technologies reviewed in this report. This information has been drawn primarily from three sources:

VERSAR, INCORPORATED, "Mobile Treatment Technologies for Superfund Wastes," U.S. EPA Report No. 540/2-86/003 (f), NTIS PB No. 87-110656, September 1986.

ONTARIO WASTE MANAGEMENT CORPORATION, "Identification and Evaluation of Mobile Technologies for Treatment of Industrial/Hazardous Wastes in the Province of Ontario," November 1987.

DUXBURY, D., "Transportable Treatment Unit Technologies, A Business Review," Centre for Environmental Management, Tufts University, July 1986.

and supplemented with information drawn from Reid Crowther's files. No representation is either made or implied that this list is complete.

WASTE RECOVERY TECHNOLOGIES

Name and Contact	Technology
CF Systems Corporation 25 Acorn Park Cambridge, MA 02140 Thomas Cody (617) 492-1631	- organics extraction
Daetwyler Corporation 310 Oser Avenue Hauppauge, New York 11788 Robin Feldman (516) 231-3232	- solvent distillation
Dedert Corporation 20000 Governors Dr. Olympia Fields, IL 60461-1074 Kay Burghard (312) 747-7000	- solvent evaporators, distillation units, activated carbon adsorption

WASTE RECOVERY TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
Edwards Engineering Corp. 101 Alexander Avenue Pompton Plains, NJ 07444 Rich Waldrop (201) 835-2808	- solvent vapour recovery
Finish Engineering Co. 921 Greengarden Road Erie, Pennsylvania 16501 Canadian Distributor: Parkes Scientific Canada 76 Quesnell Road Edmonton, Alberta T5R 5N2 Lance Parkes (403) 484-1849	- solvent distillation
Solvent Recovery Systems Inc. 459 Olive Street Winnipeg, Manitoba R3J 2X9 Curtis George (204) 837-3746	- solvent distillation
Zenon Envionment Inc. 845 Harrington Court Burlington, Ontario L7N 3P3 Thomas Krug (416) 639-6320	- reverse osmosis

STORAGE AND TRANSFER TECHNOLOGIES

Name and Contact	Technology
Bondico Inc. 2410 Silver Street Jacksonville, FL 32206 (904) 358-2602 Canadian Distributor: Advance Fire and Safety 315A Dewdney Avenue Regina, Saskatchewan S4N 0E7 (306) 525-9505	- polyethylene overpacks

STORAGE AND TRANSFER TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
Chemical Handling Equipment Co., Inc. 5451 Enterprise Blvd. Toledo, OH 43612 Tom Maro (419) 729-3935	- polyethylene containers
Environmental Container Corporation P.O. Box 161 Delafield, WI 53018-0161 Jim Caldwell (414) 646-2480	- storage units
Essex Environmental Industries, Inc. 10500 Tube Drive Hurst, TX 76053-7910 (800) 423-8188	
Galbreath P.O. Box 220 Winmac, Indiana 46996 (219) 946-6631	- roll-off containers
Greif Bros. Corporation 140 Mountain Avenue Springfield, NJ 07081 Joe Grebe (201) 688-2222	- drums and overpacks (fibre, steel, plastic)
Kentain Products Limited 55 Howard Place Kitchener, Ontario N2K 2Z4 Ken Lippert (519) 576-0994	- container liners
Packaging Research and Design Corp. P.O. Box 678 Madison, Wisconsin 39110-0678 William Beck (601) 856-9791	- trailer liners

STORAGE AND TRANSFER TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
Safety Storage, Inc. 18900 Stevens Creek Blvd. Cupertino, CA 95014 (408) 252-2750 Canadian Distributor: D.W. International Marketing Co. 27 Seaton Drive Aurora, Ontario L4G 2J9 Bill Finn (416) 727-1213	- storage buildings
Sonoco Fibre Drum Inc. One Parkway Centre 1850 Parkway Place Suite 820 Marietta, GA 30067 (404) 423-2500	- fibre drums and steel overpacks

THERMAL DESTRUCTION TECHNOLOGIES

Name	Contact
ARI International 600 North First Bank Drive Palatine, IL, 60067	William M. Scheffer (312) 359-7810
DETOXCO 2700 Ygnacio Valley Road Walnut Creek, CA	Robert McMahon (415) 930-7997
ENSCO Environmental Services First Tennessee Bank Bldg. Third Floor Franklin, TN	Robert McCormack (615) 794-1351
Envirite Field Services Atlanta, GA	Thomas McGovan (404) 627-3666
GA Technologies Inc. P.O. Box 85608 San Diego, CA 92138	Harold Diot (619) 455-3000
Haztech 5280 Panola Industrial Blvd. Decatur, GA 30035	Saul Furstein (404) 981-9332

THERMAL DESTRUCTION TECHNOLOGIES (Cont'd.)

Name	Contact
J.M. Huber Corporation P.O. Box 2831 Borger, TX 79008	Jimmy W. Boyd (806) 274-6331
Intermation Waste Energy Systems 2150 Kienlen Street St. Louis, MO 63121	D.C. Brown (314) 389-7275
John Zink Services 4401 S. Peoria Avenue P.O. Box 702220 Tulsa, OK	Kenneth Hastings (918) 747-1371
MAECORP Inc. 17450 South Halsted Street Homewood, IL 60430	Hank Mandosa (312) 957-7600
Modar Inc. 320 Wilcrest Street, Suite 220 Houston, TX 7042	Fred Sieber (713) 785-5615
OGDEN Environmental Services, Inc. P.O. Box 85178 San Diego, CA 92138-5178	Harold R. Diot (619) 455-2383
OH Materials P.O. Box 551 Findley, OH 45839	Sam Insallaco (419) 423-3526
Rollins Environmental Services 1 Rollins Plaza Wilmington, DE 19899	Bill Philipbar (302) 479-2700
Reidel Environmental Services P.O. Box 5007 Portland, OR 97205	Jack Patterson (503) 286-4656
Shirco Infrared Systems Inc. 1195 Empire Central Dallas, TX 75247-4301	George Bay (214) 630-7511
Sitex Corp. 231 Biniston, #560 Clayton, MO 63105	(314) 862-0010

THERMAL DESTRUCTION TECHNOLOGIES (Cont'd.)

Name	Contact
SYSTECH Corporation 245 North Valley Road Xenia, OH 45385-9354	Melvin C. Eifert (518) 372-8077
Trade Waste Incineration Division of Chemical Waste Management 8000 Maryland, Suite 4400 St. Louis, MO 63105	A.J. McCoy (314) 727-5040
VerTech Treatment Systems 12000 Pecos Street Denver, CO 90234	Fran Ferraro (303) 987-8800
Vesta Technology Ltd 2501 E. Commercial Blvd Suite 209 Ft. Lauderdale, FL 33308	Tricia Jack (305) 776-0330
Waste-Tech Services Inc. 445 Union Blvd., Suite 223 Lakewood, CO 80228	Elliot Cooper (303) 987-1790
Westinghouse Plasma Systems P.O. Box 350 Madison, PA 15563	Bill Mellili (412) 722-5637
Winston Technology 6920 N.W. 44th Ct. Lauderhill, FL 33319	Patrick Philips (305) 748-1769
Zimpro Inc. Military Road Rothchild, WI 54474	J. Robert Nicholson (715) 359-7211

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES

Name and Contact	Technology
Accurex Cincinnati, OH Jim Thompson (415) 964-3200	- could not contact

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
Advanced Mineral Technologies 5920 McIntyre Street Golden, CO 80403 (303) 425-0260	- adsorption, patented organic based
Andco Environmental Processes, Inc. 595 Commerce Drive Amherst, NY 14150 Jack Reich (716) 691-2100	- precipitation, (electro-chemical for fluorides, phenols and heavy metals
Bird Environmental Systems 100 Neponset Street South Walpole, MA 01071 Larry Conant (508) 668-0400	- all technologies
Calgon Carbon Corporation P.O. Box 717 Pittsburgh, PA 15230 Joseph Rizzo (412) 787-6700	- could not contact
Chemical Waste Management 150 West 137th Street Riverdale, IL 60627 (312) 218-1500	- solvent extraction
Critical Fluid Systems 25 Acorn Park Cambridge, MA 02140 Tom Cody (617) 890-1200	- solvent extraction
DETOX, Inc. Dayton, OH 45459 Evan Nyer (513) 433-7394	- air stripping - air stream: carbon and biological - activated carbon adsorption - oxidation - UV zone - precipitation
Ecolochem, Inc. 4545 Patent Road P.O. Box 12775 Norfolk, VA 23502 Richard Smallwood (804) 855-9000	- reverse osmosis - filtration - ion exchange - redox - condensate polishing

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
ENSR Operations 3100 Steles Markham, Ontario L3R 4T3 (416) 479-1433	- chemical PCB destruction on site
Ensotech, Inc. 11550 Vanowen Street North Hollywood, CA 91605 Don Aberg (818) 767-2222	- air stripping, with carbon - oxidation, patented - fixation
Industrial Innovations, Inc. P.O. Box 830 Stockton, CA 95201 Alfred Abila (209) 462-8241	- phase separation - centrifuging
Interim Dewatering Services 200 Monroe Turnpike Monroe, CT 06468 Ron Ing (203) 261-4458	- could not contact
IT Corporation 4575 Pacheco Blvd. Martinez, CA 94553 Ted Felman (415) 372-9100	- all technologies
Kipin Industries 513 Green Garden Road Aliquippa, PA 15001 Peter Kipin (412) 495-6200	- distillation, electrical - fuel from sludge solidification - high volume incineration
Metropolitan Environmental Suite 615 101 Queensway West Mississauga, Ontario L5B 2P7 Hugh Carr-Harris (416) 896-2100	- mobile filtration for sludge volume reduction

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
Mobile Solvent Reclaimers RR #1 St. Joseph, MO 64507 Larry Lambing (816) 232-3972	- could not contact
MTA Remedial Resources 1511 Washington Avenue Golden, CO 80401 Rick Hogan (303) 279-4255	- filtration - phase separation - soil wash by froth flotation of chemical injection
Newpark Waste Treatment Systems 200A Bourgess Drive Broussard, LA 70518 Phil Clark (713) 963-9107	- filtration - phase separation - flotation - dewatering
PPM Inc. 10 Central Avenue Kansas City, MO 66118 (816) 221-6827	- could not contact
Pressure Filtration Specialists, Inc. 400 Arbor Lake Drive P.O. Box 23657 Columbia, SC 29224 Mike Jump (803) 735-1510	- could not contact
R & B Filtration Systems Company Suite 150 2211 Newmarket Parkway Marietta, GA 30067 Doug Collins (404) 955-8780	- filtration - solvent extraction - leaching - precipitation - pH shifting
Resource Conservation Co. 3630 Cornus Lane Ellicott City, MD 21043 Lenny Weimer (301) 596-6066	- air stripping - steam stripping - soil, solids extraction

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
Resources Conservation Co. 3101 NE Northup Way Bellevue, WA 98004 Doug Austin (206) 828-2400	- solvent extraction for PCB and heavy metal contaminated oily sludge
Rexnord C.R.I.C. 5103 West Beloit Road Milwaukee, WI 53201 Gary Rolliger (414) 643-3050	- air stripping - filtration - phase separation - activated carbon - adsorption - ion exchange - membrane separation - redox - neutralization - precipitation - dechlorination
Sanexen Burlington, Ontario Naz Hijazi (416) 681-3366	- air stripping - evaporation - distillation - solvent extraction - filtration - phase separation - activated carbon adsorption - redox - precipitation - dechlorination
Roy F. Weston, Inc. Weston Way West Chester, PA 19380 Roger Nielson (215) 692-3030	- air stripping - evaporation - distillation - filtration - phase separation - activated carbon adsorption - will invest in any other
Solidtek 5371 Cook Road Morrow, GA 30260 Ed Shuster (404) 361-6181	- could not contact

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES (Cont'd.)

Name and Contact	Technology
Sunohio 1700 Gateway Blvd., S.E. Canton, OH 44707	- filtration - Redox
Terra Vac. Inc. 356 Fortaleza Street San Juan, PR 00901 Jim Malot (809) 723-9171	- vacuum filtration for soils using no excavation
Toxic Treatments 901 Mariner Island Blvd. Suite #315 San Matero, CA 94404 (415) 572-2991 Mickey Ridosh (213) 514-0881	- chemical oxidation - thermal stripping using ATW-Caldwell method

IMMOBILIZATION TECHNOLOGIES

Name	Contact
Bethlehem Steel Bldg. H-Room A110 Bethlehem, PA 18016	Robert M. McMullan (215)694-2424
Chemfix Inc. 1675 Airline Highway	Robert A. Phelan (504)467-2800
Chemical Waste Management Riverdale Center 150 W. 137th Street Riverdale, IL 60627	Peter Daley (312)841-8360
Envirite Field Services 600 Germantown Pike Plymouth Meeting, PA 19462	Bill Howard (215)825-8877
Envirochem Waste Management 975 Walnut Street Cary, NC 27511	Jerry Deakle (919)469-8490
Hazcon Inc. P.O. Box 947 Katy, TX 77492	Roy Funderburk (713)391-1085

IMMOBILIZATION TECHNOLOGIES (Cont'd.)

Name	Contact
Lopat Enterprises Inc. 1750 Bloomsbury Avenue Wanamassa, NJ 08812	Lewis Flax (210)922-6600
Resource Recovery of America Inc. Executive Plaza, Suite 23 4406 South Florida Avenue Lakeland, FL 13303	Robert O'Kinbart (813)644-7700
Solidtek systems, Inc. 5371 Cook Road Morrow, GA 30260	Ed Shuster (404)361-6181
Stateley Canada Inc. 760, Boulevard Industrial Blainville, Quebec J7E 4J7	John Schufield
Velsicol Chemical Corporation 2603 Corporate Avenue Suite 100 Memphis, TN 38132	Charles Hanson (901)345-1788
Westinghouse Hittman Nuclear 9151 Runsey Road Columbia, MD 21045	Robert Connor (301)964-5043
Westinghouse Waste Technology Services Div. P.O. Box 286 Madison, PA 15663	(412)722-5600

APPENDIX B

CONVERSION TABLE

APPENDIX B
CONVERSION TABLE

Multiply	By	To Obtain
mil	.0254	.mm
inch	25.4	mm
ft/s	.3048	m/s
cu. ft	28.3	L
Imperial Gallon	4.54	L
U.S. Gallon	3.79	L
cu. inch	16.4	ml
lb (mass)	.454	kg
lb (force or thrust)	4.54	N
lb (mass)	454	tonne
ppm	1	mg/kg
ppm (for water, liquids with a density close to water)	1	mg/L
lb/cu. ft.	16	kg/m^3
lb/sq. ft.	4.88	kg/m^2
psi	6.89	kPa
centipoise (dynamic viscosity)	1	mPa·s
Btu	1.055	kJ
Btu/lb	2.33	kJ/kg
Btu/cu. ft.	37.3	kJ/m^3
Btu/h	.293	W